Forecasting Wind Energy Costs and Cost Drivers

The Views of the World's Leading Experts

Full Summary of Survey Results

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iea wind

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https://emp.lbl.gov/iea-wind-expert-survey

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Presentation Overview

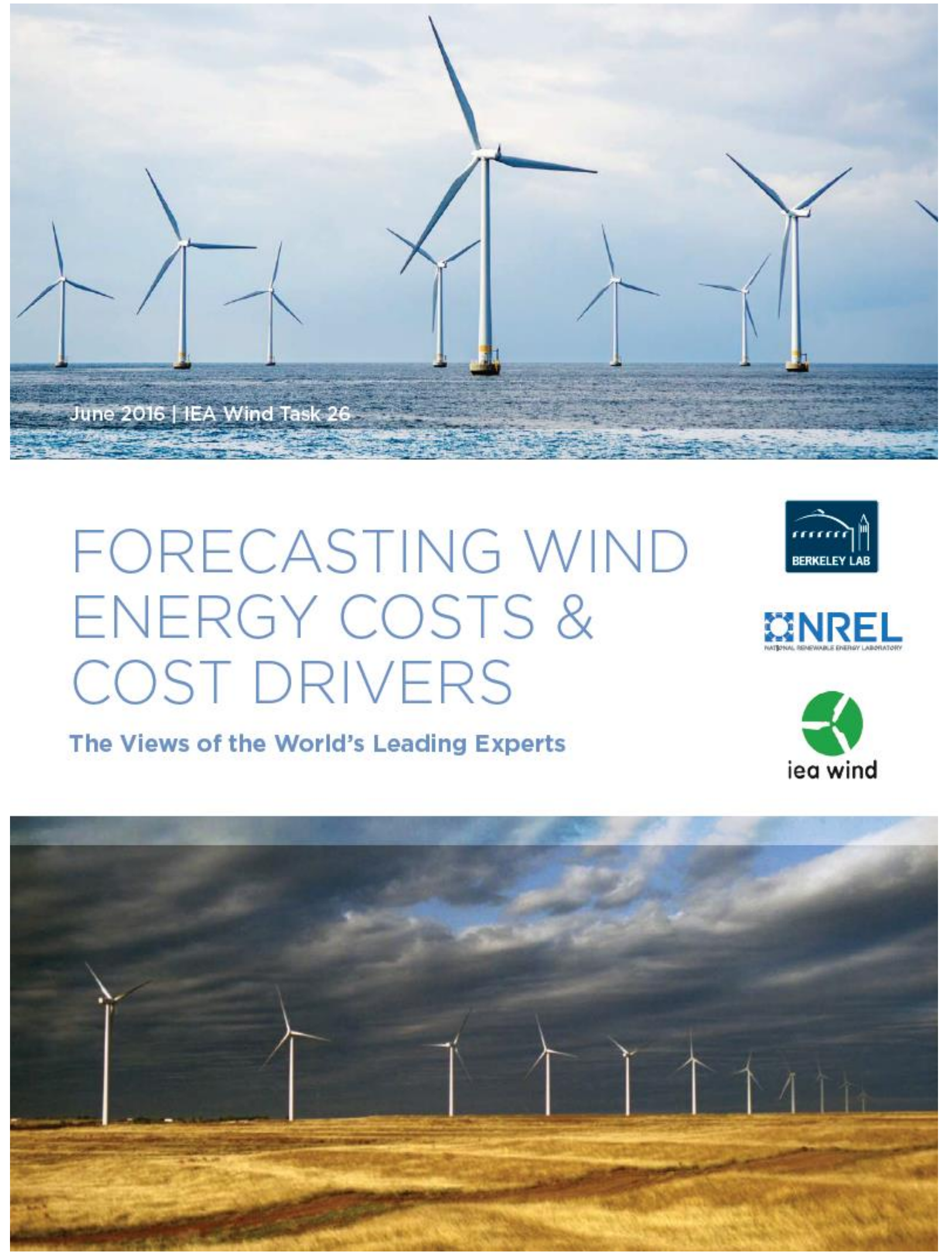
Executive Summary

Survey Overview & Implementation

IEA Wind Task 26 Survey Results

- Overall LCOE reduction
- Baseline LCOE values
- LCOE reduction factors
- Turbine characteristics
- Advancement expectations
- Broad market drivers
- Literature comparisons

Appendix: Additional Tables/Figures



Executive Summary: *Overview of Elicitation Survey*

BERKELEY LAB

What

Expert survey to gain insight on possible magnitude of future wind energy cost reductions, sources of reductions, and enabling conditions needed to realize continued innovation and lower costs

Covering onshore, fixed-bottom offshore, and floating offshore wind

Why

Inform policy & planning, R&D, and industry investment & strategy development while also improving treatment of wind in energy-sector models

Complement other tools for evaluating cost reduction, including learning curves, engineering assessments, other means of synthesizing expert knowledge

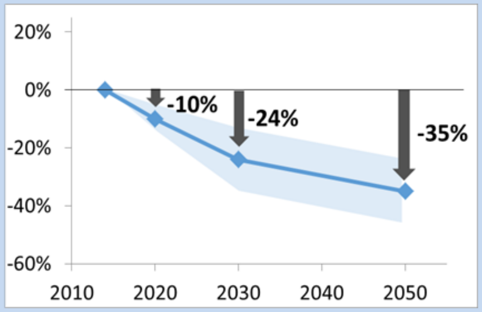
Who

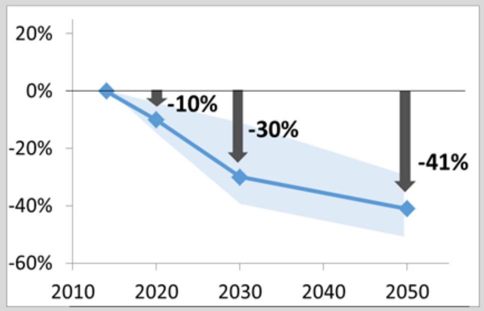
Largest single expert elicitation ever performed on an energy technology in terms of expert participation: 163 of the world's foremost wind energy experts

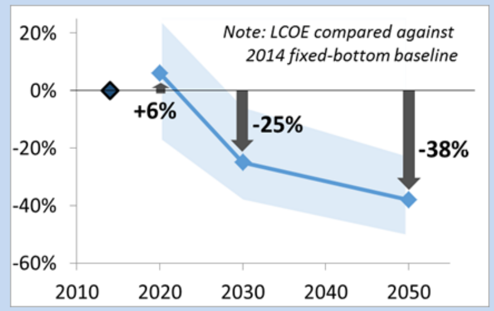
Led by LBNL and NREL, under auspices of IEA Wind Task 26 on "Cost of Wind Energy," and with numerous critical advisers throughout

Executive Summary:
Infographic Summary of Key Results

	ONSHORE (LAND-BASED)	FIXED-BOTTOM OFFSHORE	FLOATING OFFSHORE
LEVELIZED COST OF ENERGY (median estimates for median scenario & 1st-3rd quartile range)	See chart below	See chart below	See chart below
DRIVERS FOR COST REDUCTION IN 2030 (median estimates; median scenario)	Capacity factor: +10% Project life: +10% CapEx: -12% OpEx: -9% WACC: no Δ	Capacity factor: +4% Project life: +15% CapEx: -14% OpEx: -9% WACC: -10%	Capacity factor: +9% Project life: +25% CapEx: -5% OpEx: -8% WACC: -5%
TURBINE SIZE IN 2030 (typical projects)	3.25 MW 115 m hub height 135 m rotor diameter	11 MW 125 m hub height 190 m rotor diameter	9 MW 125 m hub height 190 m rotor diameter
TOP-FIVE IMPACT CATEGORIES	• Larger rotors, reduced specific power • Rotor design advancements • Taller towers • Reduced financing costs • Component durability / reliability	• Larger turbine capacity • Foundation / support structure design • Reduced financing costs • Economies of scale via project size • Component durability / reliability	• Foundation / support structure design • Installation process efficiencies • Foundation / support manufacturing • Economies of scale via project size • Installation / transport equipment



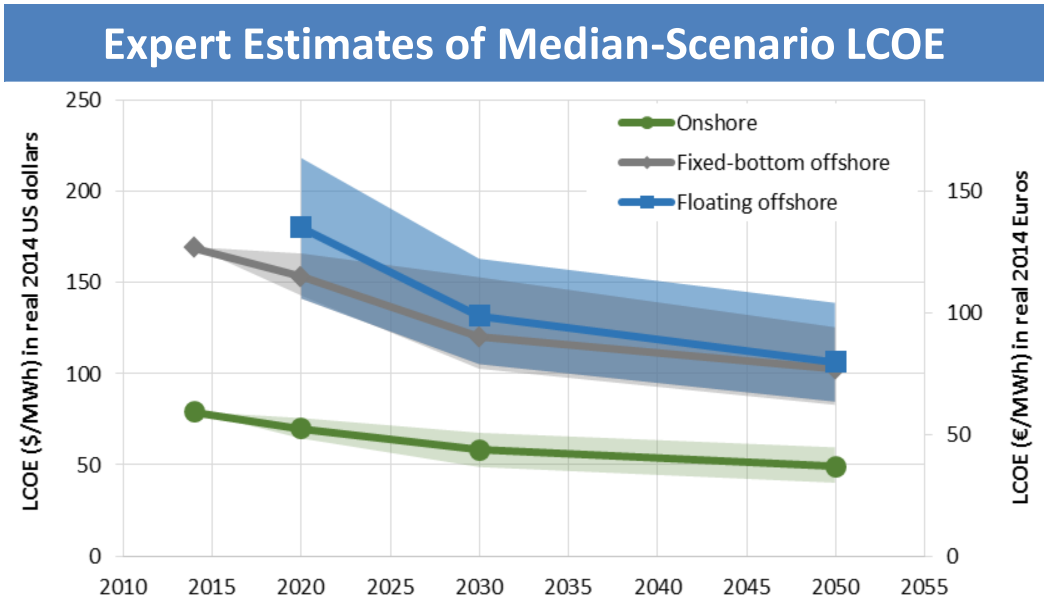




Note: All dates are based on the year in which a new wind project is commissioned

Executive Summary: ***Significant Cost Reductions Are Anticipated***

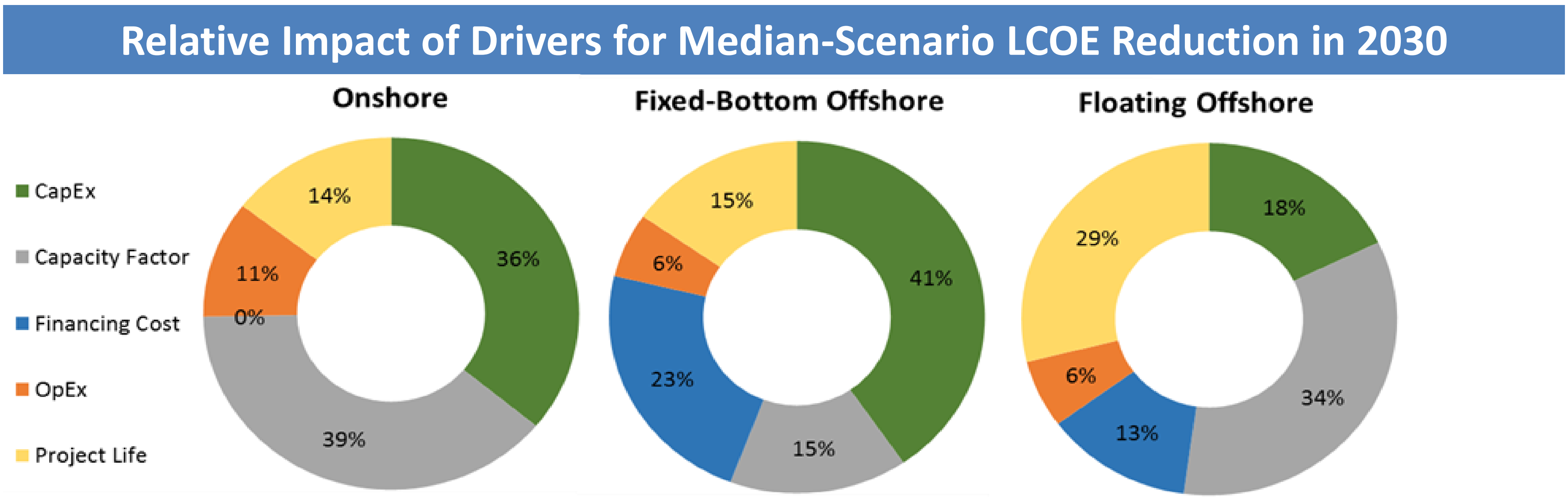
- Expert survey results show an expectation of continued reductions in the unsubsidized levelized cost of wind energy (LCOE), but uncertainty in level
- Previous slide summarizes LCOE-reduction expectations for median (50th percentile, "best guess") scenario, focusing on median of expert responses
  - Across all three wind applications, LCOE is anticipated to decline by 24%–30% in 2030 and by 35%–41% in 2050, relative to expert-specific 2014 baseline values
- Percentage changes from baseline are most broadly applicable way to present findings, but in relative absolute terms, onshore wind is expected to remain less expensive than offshore wind and fixed-bottom offshore expensive than floating offshore
  - However, there are greater absolute reductions (and more uncertainty) in the LCOE of offshore wind compared with onshore, and a narrowing gap between fixed-bottom and floating offshore, with especially sizable anticipated reductions in the LCOE of floating offshore from 2020 - 2030



Lines/markers indicate the median expert response for the **median LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

Executive Summary: ***Drivers of Cost Reduction Are Diverse (1)***

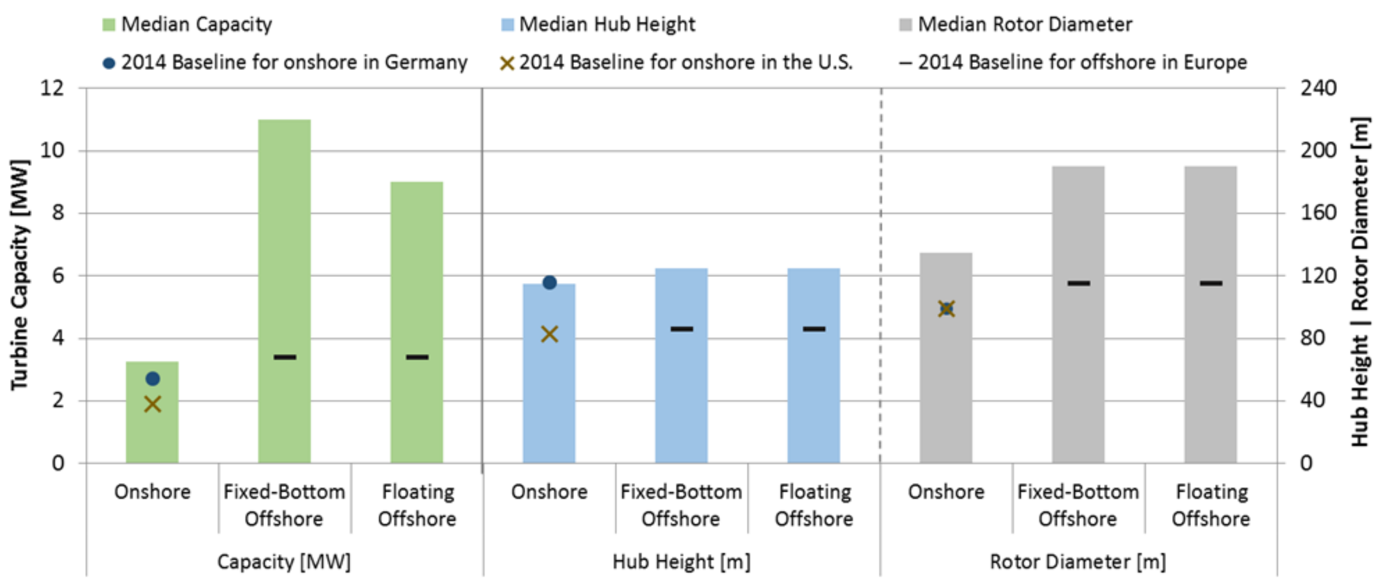
- Earlier infographic summarizes expert views on how the median scenario LCOE reductions between 2014 and 2030 might be achieved, in terms of capital costs (CapEx), operating costs (OpEx), capacity factors, project design life, and cost of finance (weighted average cost of capital, WACC)
- Relative impact of changes in each driver on LCOE reduction shown below:
  - Onshore: CapEx and capacity factor are dominant drivers of LCOE reduction
  - Fixed-bottom offshore: CapEx and improvements in financing are largest contributors
  - Floating offshore: Larger role for capacity factor improvements, relative to fixed bottom



Executive Summary: ***Drivers of Cost Reduction Are Diverse (2)***

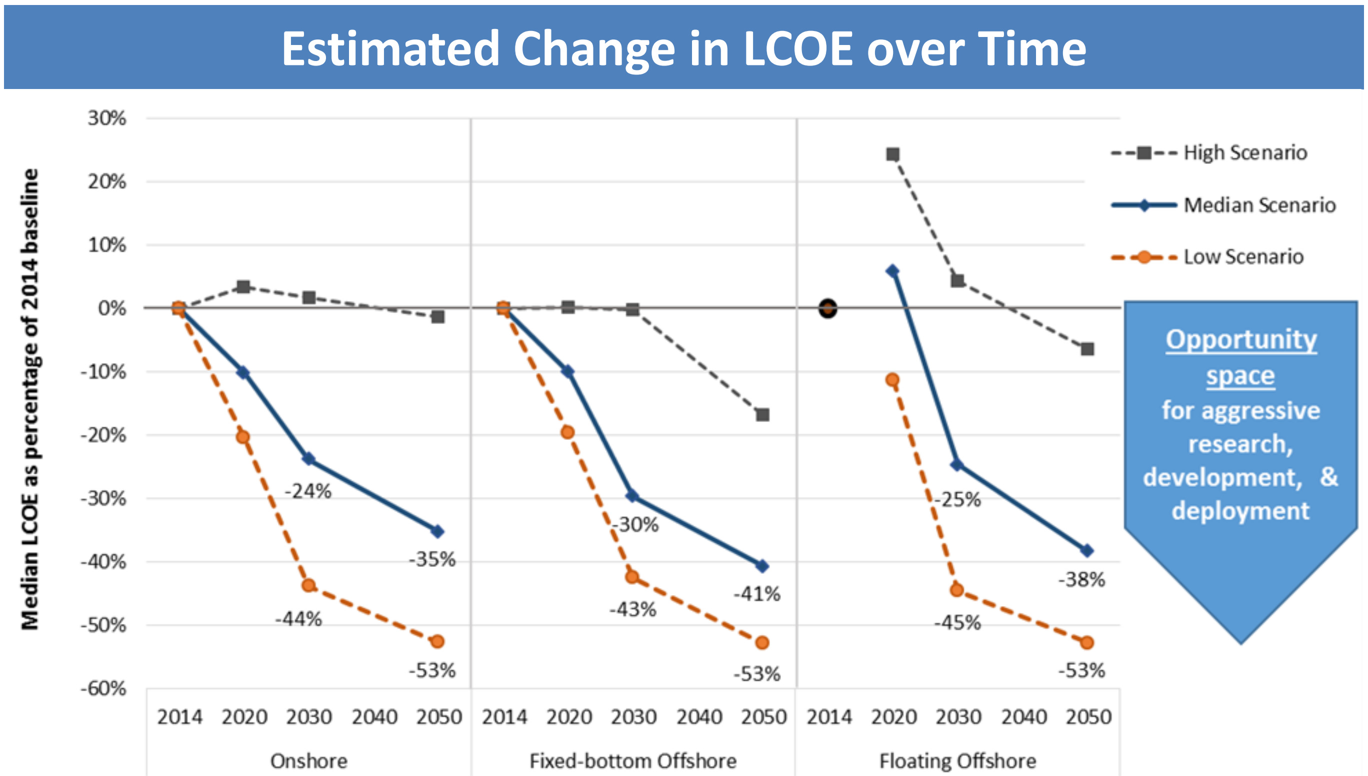
- Earlier infographic summarizes expected "typical" turbine size across all three wind applications in 2030, with more details provided below
- Importance of higher capacity factors for onshore wind as shown on previous slide is reflected in views on turbine characteristics, with scaling expected in capacity ratings, but especially rotor diameters and hub heights (with drop in specific power)
- Relatively higher importance of CapEx and lower importance of capacity factor for fixed-bottom offshore is consistent with opinions on offshore turbine size, where significant growth in nameplate ratings (and hub heights) is anticipated in order to minimize CapEx, but specific power is expected to remain roughly at recent levels

Wind Turbine Characteristics in 2030 for All Three Wind Applications



Executive Summary: ***Opportunity Space for Greater Cost Reductions Is Sizable***

- Sought insight not only on the median LCOE scenario, but also on less-likely scenarios for high and low future LCOEs
- Sizable resulting range in expert-specified LCOEs suggests significant uncertainty in degree and timing of future advancements
- Managing this uncertainty is—at least partially—within the control of decision makers; low scenario represents what might be possible with aggressive RD&D
- Survey results further show that “learning with market growth” and “research and development” are the two most-significant enablers for the low LCOE scenario

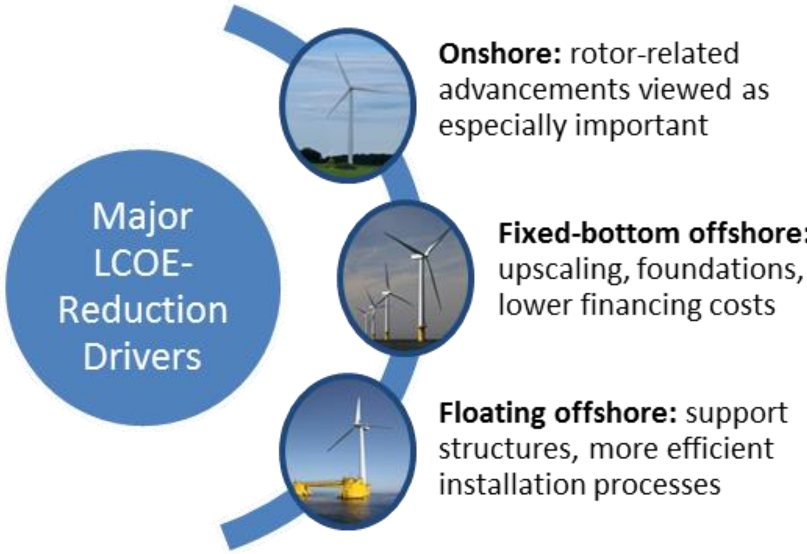


Executive Summary: ***Many Advancement Opportunities Exist***

- Respondents rated 28 different wind technology, market, and other drivers based on their expected impact on LCOE reductions by 2030, separately for onshore, fixed-bottom offshore, and floating offshore wind; top-5 listed in infographic, and a general summary of findings is shown below

- Top impact categories for onshore focused on improving capacity factors via larger rotors and related advancements, and increased hub height

- For fixed-bottom offshore, most highly rated advancements include increased turbine capacity ratings, design advancements for foundations & support structures, and reduced financing costs & contingencies

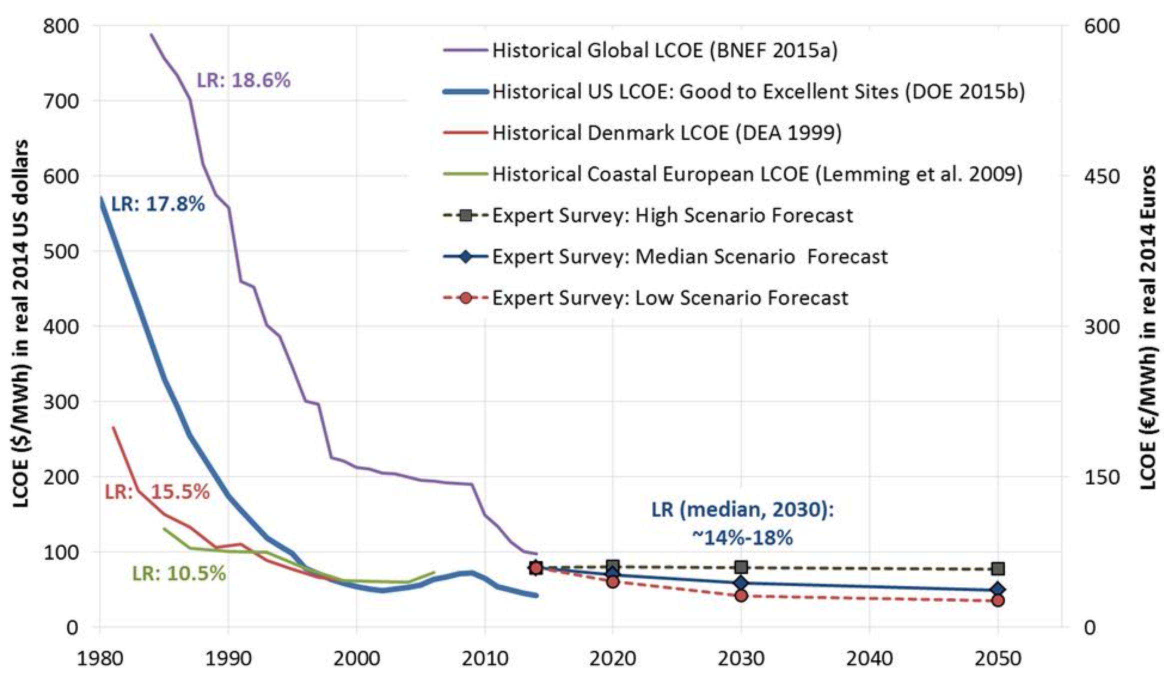


- Some similar items rate highly for floating offshore, with an even greater emphasis on foundations & support structures as well as installation

Executive Summary: ***Survey Results Broadly Consistent w/ Historical Onshore Wind LCOE***

- Though expert elicitation as a method is subject to possible bias and over-confidence, and notwithstanding the sizable range in LCOEs, survey results are broadly consistent with historical LCOE trends for onshore wind
- Figure depicts four separate estimates of historical onshore wind LCOE and associated single-factor learning rates (LRs = 10.5%–18.6%, meaning that LCOE declines by this amount for each doubling of global cumulative wind capacity)
- Implicit learning rate embedded in the median-scenario LCOE forecast from our experts to 2030 (about 14%–18%) is squarely within the range of these past, long-term learning trends for onshore LCOE
- Findings on offshore LCOE suggest that experts either anticipate lower offshore-only learning (relative to learning for onshore) or expect learning spillovers from on- to off-shore

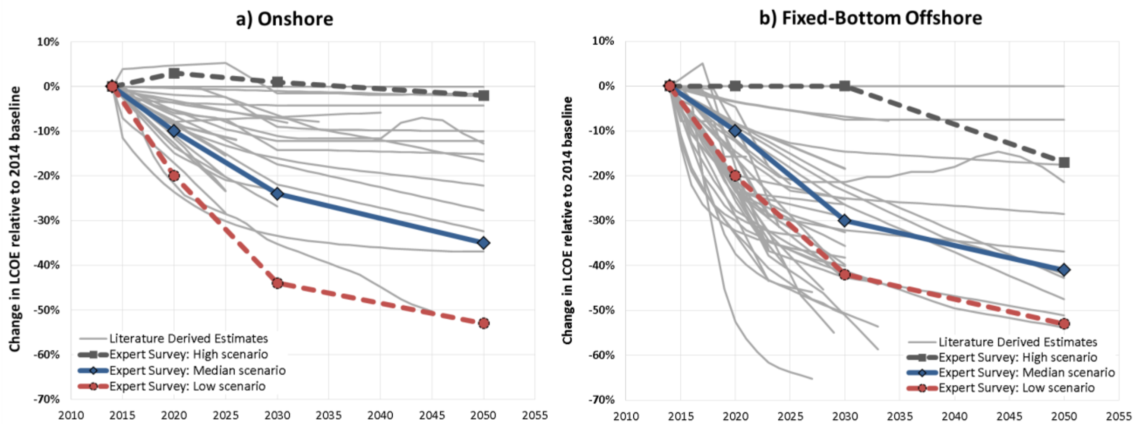
Historical and Forecasted Onshore Wind LCOE and Learning Rates



Executive Summary: ***Survey Results Differ Somewhat from Other Cost Forecasts***

- Elicitation results are compared to other wind LCOE forecasts in figure below
- Survey results broadly within the range of other forecasts, but elicitation shows:
  - Larger expected onshore wind LCOE reduction than much of literature
  - Smaller expected offshore wind LCOE reduction than much of literature

Estimated Change in LCOE:
Expert Survey Results vs. Other Forecasts



- Previous onshore learning comparison suggests that properly constructed learning rates may be used to forecast future costs for more mature applications
- Majority of literature focuses on CapEx learning, however, with onshore LRs of 6%-9%: well below historical LCOE learning and survey findings; survey clearly shows CapEx improvements to be only one means of achieving lower LCOE
- If used to forecast future costs, LCOE-based learning should be applied; use of CapEx learning may explain relative conservatism of other onshore forecasts

Survey Overview & Implementation

Background

Wind energy has grown rapidly, supported by policies and facilitated by technology advancements and cost reductions

Long-term contribution that wind makes to energy supply, and need for ongoing policy support, depends—in part—on future costs of onshore & offshore wind

Sizable uncertainty about degree of future cost reduction, and conditions that might drive greater reduction

Broad Goals of IEA Wind Task 26 Survey

Implement expert elicitation survey on future wind energy costs and technology advancement possibilities…

… informing policy & planning decisions, public and private R&D decisions, industry investment and strategy development, and electric sector modeling assumptions

Leveraging one of several complementary methods to help understand wind technology & cost reduction pathways

- learning curves
- engineering assessments
- **expert knowledge**

Specific Goals of Survey

Conduct survey of wind energy experts to gain insight on:

- magnitude of possible future wind energy cost reductions
- sources of future cost reductions
- enabling conditions to realize innovation and lower costs

Compare insights for onshore (land-based), fixed-bottom offshore, and floating offshore wind; and to existing literature

Compare views: between leading-expert group vs. larger overall sample (minus the leading group), by organizational type, by application coverage, by type of expertise, and by familiarity with different geographic regions

Survey Leadership

IEA Wind Task 26

- Conducted under auspices of IEA Wind “Cost of Wind Energy”, and its member countries (US, Denmark, Germany, Ireland, Netherlands, Norway, Sweden, UK, European Commission)

Survey Leadership Team

- Ryan Wiser and Joachim Seel (LBNL); Karen Jenni (Insight Decisions); Maureen Hand, Eric Lantz and Aaron Smith (NREL); Erin Baker (U Mass. Amherst)

Other IEA Wind Task 26 Advisors

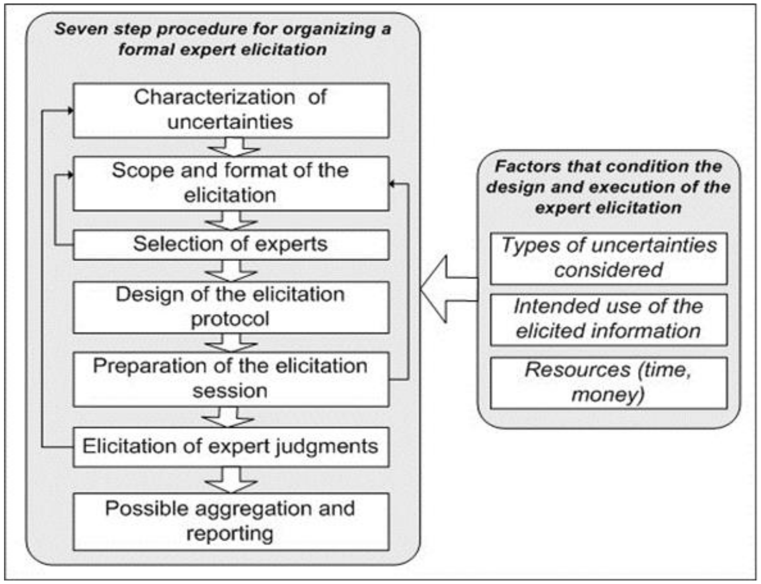
- Berkhout, Duffy, Cleary, Lacal-Arántegui, Husabø, Lemming, Lüers, Mast, Musial, Prinsen, Skytte, Smart, Smith, Sperstad, Veers, Vitina, Weir

Online Survey Platform

- Survey implemented online via Near Zero platform

Our Approach: Expert Elicitation

- Online survey of large sample of the world's foremost wind experts under auspices of IEA Wind Task 26 on the "Cost of Wind Energy"
- One of the first efforts to use "formal" expert elicitation methods to understand wind energy cost reduction potential *(many previous efforts have leveraged expert knowledge)*
- Expert elicitation is a tool—with established protocols—to develop estimates of unknown or uncertain quantities based on careful assessment of the knowledge and beliefs of subject-matter experts
- "Partial" elicitation—our elicitation survey:
  - Casts wide net via online survey to increase number of respondents
  - No comprehensive elicitation of probability distributions or technology parameters
  - No elicitation of opinions conditional on specific R&D, policy, deployment, others



The Expert Elicitation Method

- Often considered the best way to develop credible estimates when data are sparse, or when projections are sought for future conditions that are very different from past conditions
- When implemented well, insights can complement other tools:
  - **Learning curves:** causal mechanisms poorly understood; few studies on wind LCOE; historical trends may be poor guide to future; some technologies have limited historical data
  - **Engineering assessments:** opportunities captured often incremental and near-term; requires complex models to capture full array of component- and system-level interactions; rarely provides insight on probability
  - **Expert knowledge:** absent care, informal tools to extract knowledge may be particularly prone to bias and overconfidence
- Expert responses affected by design/features of data collection instrument, and by individuals selected to submit their views
  - Rich literature provides guidance on question design, importance of clarity in what is being asked, how to minimize expert motivational and cognitive biases, and importance of providing feedback to experts and providing opportunities for them to review and update their assessments

Survey Design and Implementation

Applied many basic concepts, tools, and guidelines of well-designed expert elicitation: (1) clearly defined quantities being assessed, (2) used familiar terminology and units, (3) minimized need for side calculations, (4) reduced anchoring and overconfidence biases by asking for low and high estimates before mid-point, (5) provided feedback and opportunity to review and modify responses

- early draft survey circulated for internal comment
- in-person survey pilot & expert workshop
- multiple revisions & iterations w/ internal & external experts
- survey launch announced in October 2015
- 6 waves of reminders via email and phone; Webinar
- Dec 2015: survey closed

Survey Content: What We Asked (1)

Scope of assessment comprised three applications: onshore wind, fixed-bottom offshore wind, and floating offshore wind

Central emphasis on changes in levelized cost of energy (LCOE) between baseline 2014 (where the respondent could accept a pre-defined baseline, or create their own) and 2020, 2030, and 2050 (date of commissioning)

- Including uncertainty about future: low (10^{th} percentile), high (90^{th}), median (50^{th})

For 2014 and 2030, build-up of LCOE: CapEx, OpEx, capacity factor, design life, cost of financing (nominal, after-tax WACC)

- Survey assumed tax rate (25%), depreciation (20-year straight-line), inflation (2%)

Details: *Emphasis was on "**typical**" (aka, median) projects in the region of the world each respondent was familiar with. Asked for low/median/high range based on that typical project considering technology, market and policy factors that might impact the entire wind sector but excluding project-specific factors and also excluding changes in macroeconomic conditions, materials and commodity prices, and other factors not directly related to the wind energy business.* ***CapEx:*** *asked to only include costs within plant boundary, and so to include electrical cabling within plant, but exclude substations, transmission lines, or grid interconnection costs. As such, for offshore wind, within-plant array cabling included, but offshore substation, any HVDC collector stations and associated cables, and costs for grid connection to land excluded.* ***OpEx*** *excludes any costs associated with grid interconnection, substations, or transmission usage.*

Survey Content: What We Asked (2)

Expectations for turbine characteristics in 2030: capacity, rotor diameter, hub height

Development, technology, design, manufacturing, construction, operational, & market changes expected to contribute the most to reducing LCOE by 2030

Broad drivers most likely to facilitate achieving “low” scenario estimates of LCOE in 2030 as opposed to “median” scenario estimates in that year

Respondent “demographics” to allow comparisons across groups, and survey branching questions on wind application areas and currency

- Data reported in real currency: USD and Euro
- Used average 2014 exchange rate of € 1= US $1.33

Targeted Survey Respondents

Global survey: identified 482 possible survey respondents from IEA Task 26 members, affiliated organizations, others

Of these, selected smaller group of 42 uniquely-qualified “leading” experts to mirror more-traditional elicitation

Casting a Wide Net

- sought relatively wide distribution of survey

Ideal Respondent

- strategic, system-level thought leaders, w/ wind tech, cost, market expertise

Respondent Type

- industry, R&D institutions, academia, others

Technology Specialization

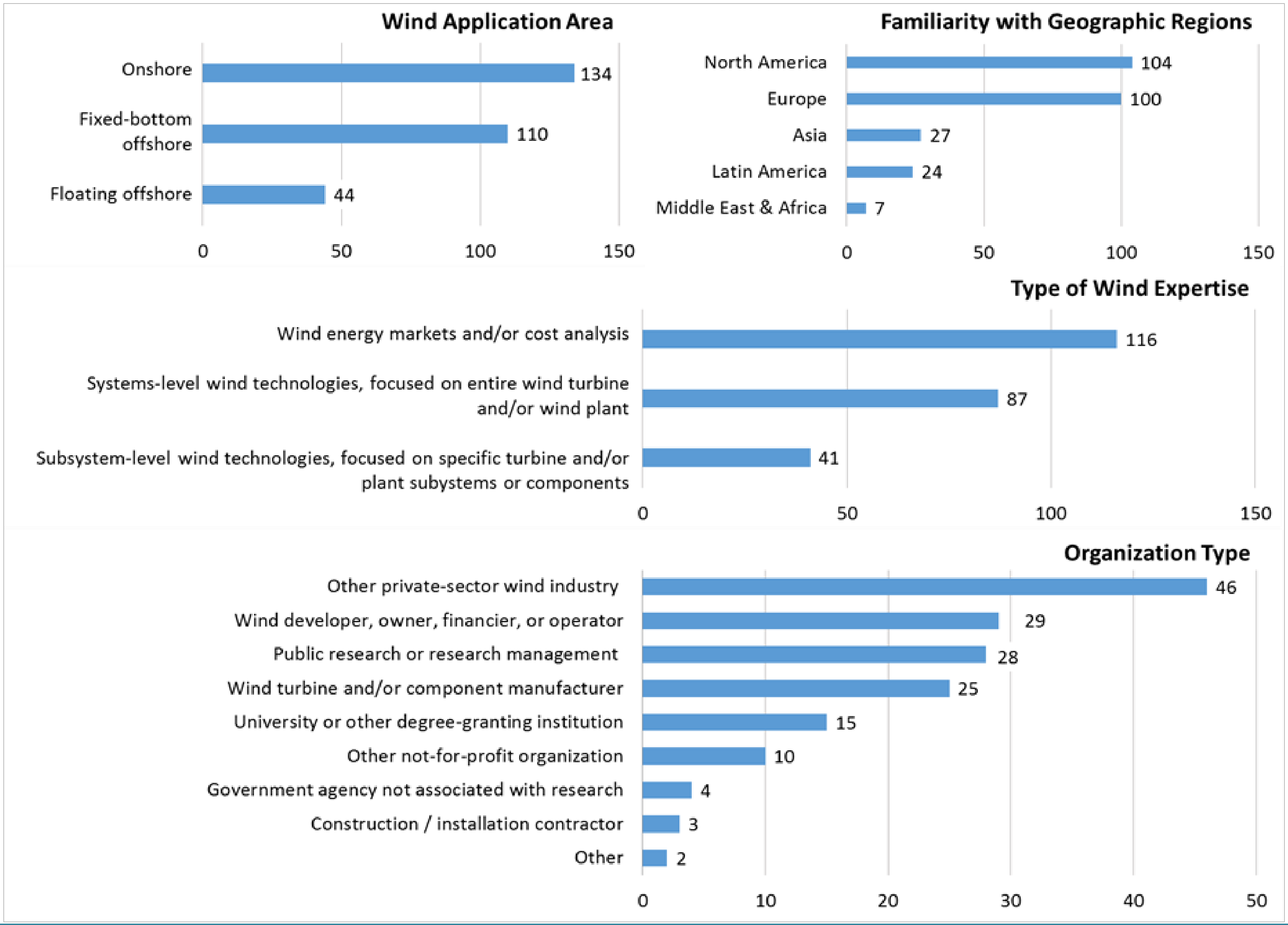
- onshore, fixed-bottom offshore, floating offshore

Geography

- primarily Europe and U.S., but did not foreclose other regions

Actual Respondents: 163 (34% response rate), Including 22 from Leading-Expert Group (52%)

Response rate: Strong overall response & broad cross-section of wind experts; median expert dedicated 49 minutes to survey; largest single expert elicitation ever performed on an energy technology



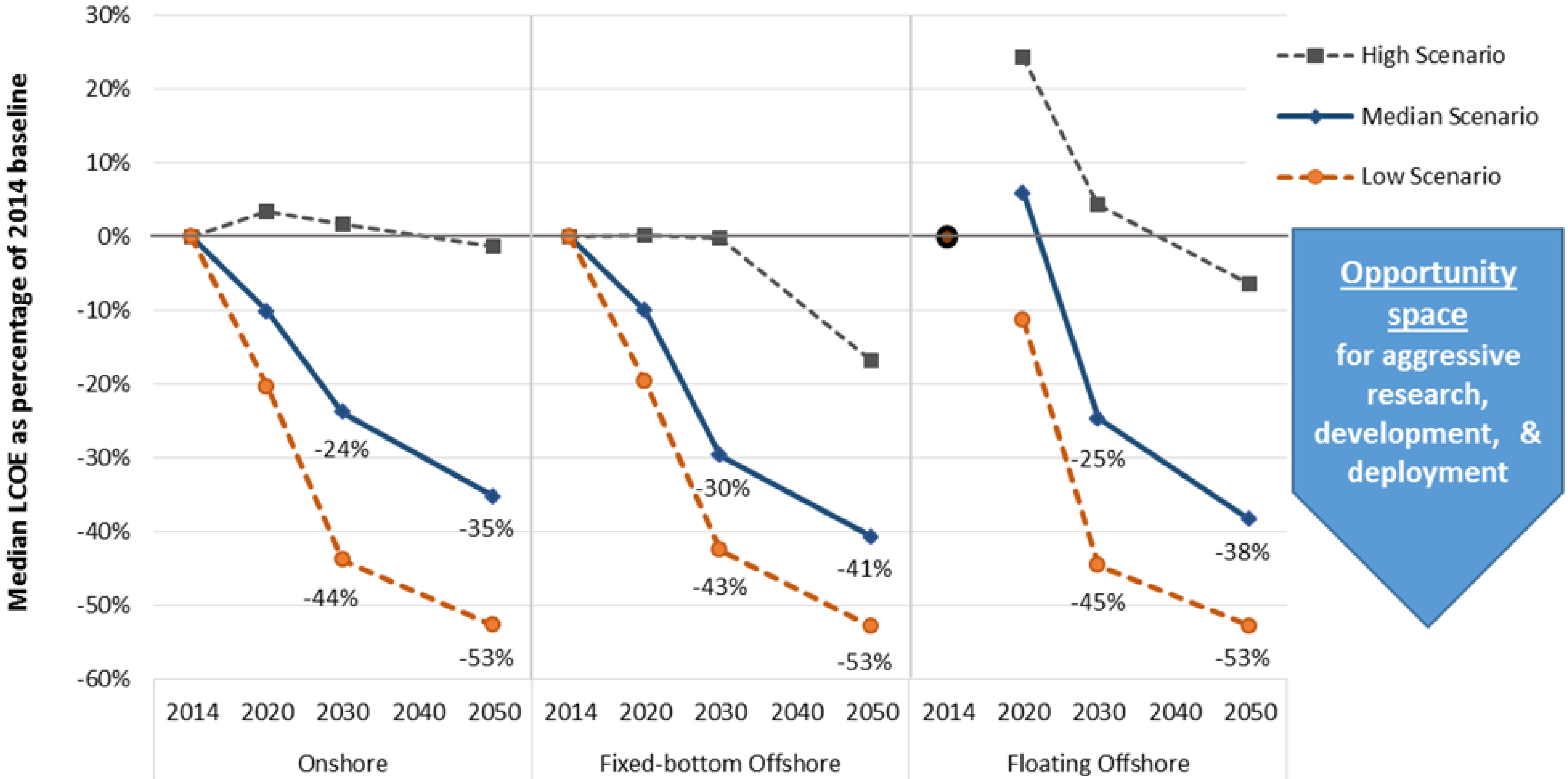
IEA Wind Task 26 Survey Results

Structure of Results Presentation

- Forecasts for overall LCOE reduction: 2014 baseline through 2050
- Baseline values: LCOE baseline for 2014
- LCOE reduction: CapEx, OpEx, capacity factor, lifetime, WACC; 2014 to 2030
- Turbine characteristics: nameplate capacity, rotor diameter, hub height in 2030
- Relative impact of technology, market, and other changes on LCOE in 2030
- Ranking of broad drivers for achieving low LCOE in 2030
- Comparison of LCOE reduction survey results with broader literature

Overall LCOE Reduction, 2014-2050: ***Summary Across All Applications***

Significant uncertainty in, but large opportunity for, cost reduction



Note: Floating offshore compared against 2014 baseline for fixed-bottom offshore. All dates are based on the year in which a new wind project is commissioned

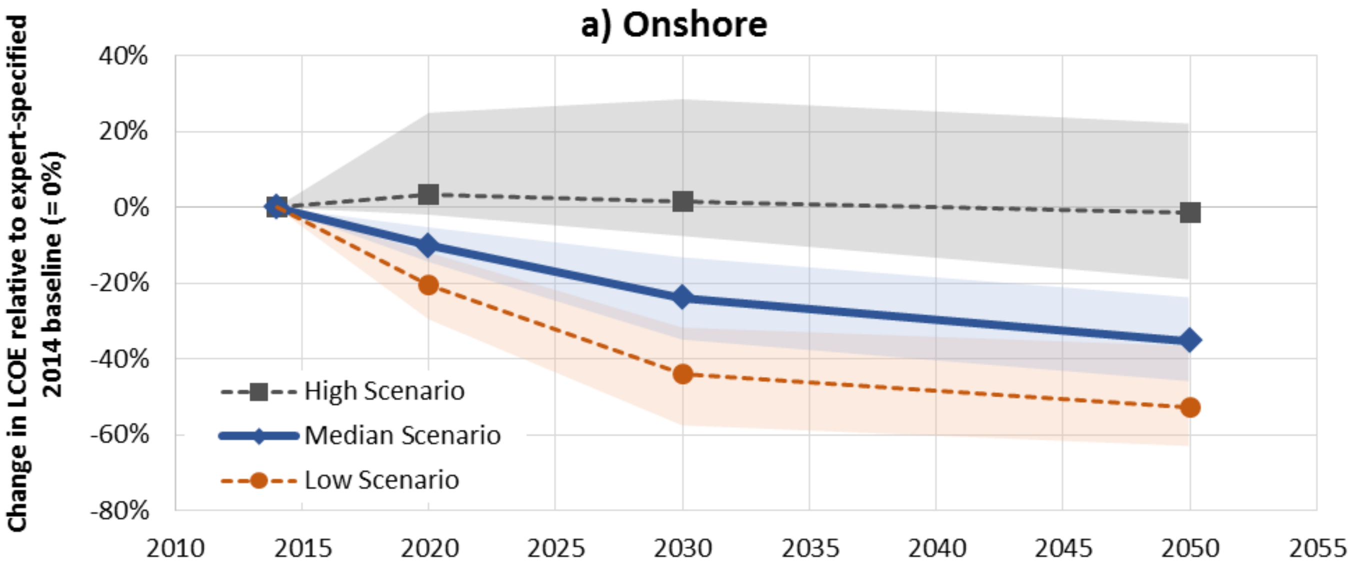
Overall LCOE Reduction, 2014-2050: *Onshore, Land-Based Wind*

Onshore wind relatively mature, but experts anticipate further advancements

In median scenario, median respondent predicts LCOE reduction of: 10% in 2020, 24% in 2030, 35% in 2050

Range between high, median, low scenarios demonstrate large “opportunity space”: low scenario reduction of 44% in 2030, 53% in 2050

Sizable range of uncertainty



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses

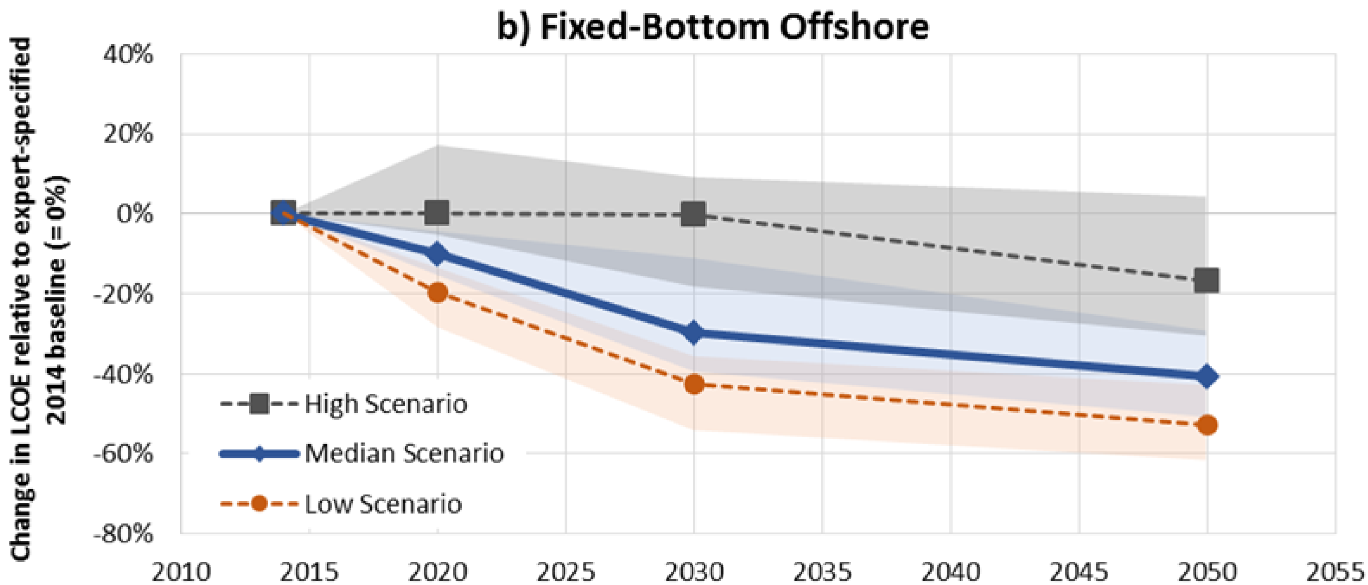
Overall LCOE Reduction, 2014-2050: ***Fixed-Bottom Offshore Wind***

Percentage reduction greater than onshore under high and median scenarios in 2030/2050; similar in low

In median scenario, median respondent predicts LCOE reduction of: 10% in 2020, 30% in 2030, 41% in 2050

Range between high, median, low scenarios demonstrate large "opportunity space": low scenario reduction of 43% in 2030, 53% in 2050

Sizable range of uncertainty



Lines/markers indicate the **median** expert response
Shaded areas show the 1st-3rd quartile range of expert responses

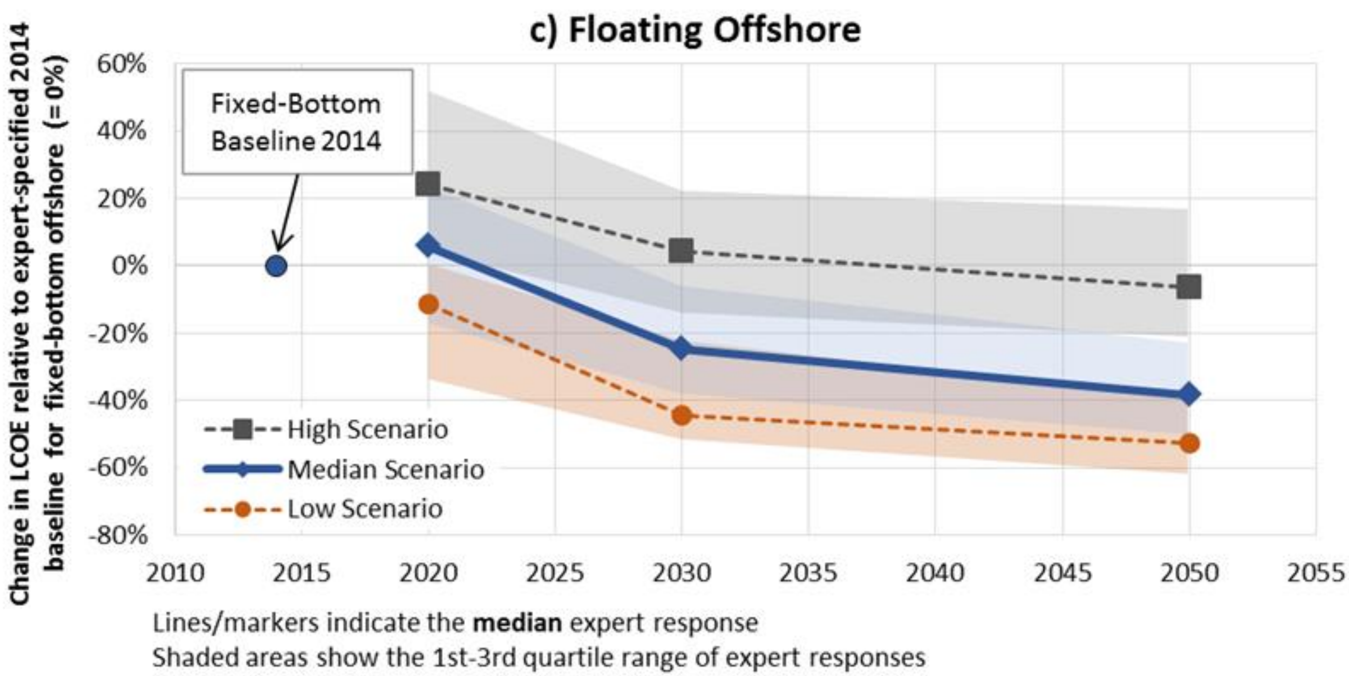
Overall LCOE Reduction, 2014-2050: ***Floating Offshore Wind***

Trends reasonably similar to fixed-bottom, except higher LCOE in near-term (e.g., 6% higher in median case than 2014 baseline)

In median scenario, median respondent predicts LCOE reduction of: 25% in 2030 and 38% in 2050

Range between high, median, low scenarios demonstrate large "opportunity space": low scenario reduction of 45% in 2030, 53% in 2050

Sizable range of uncertainty



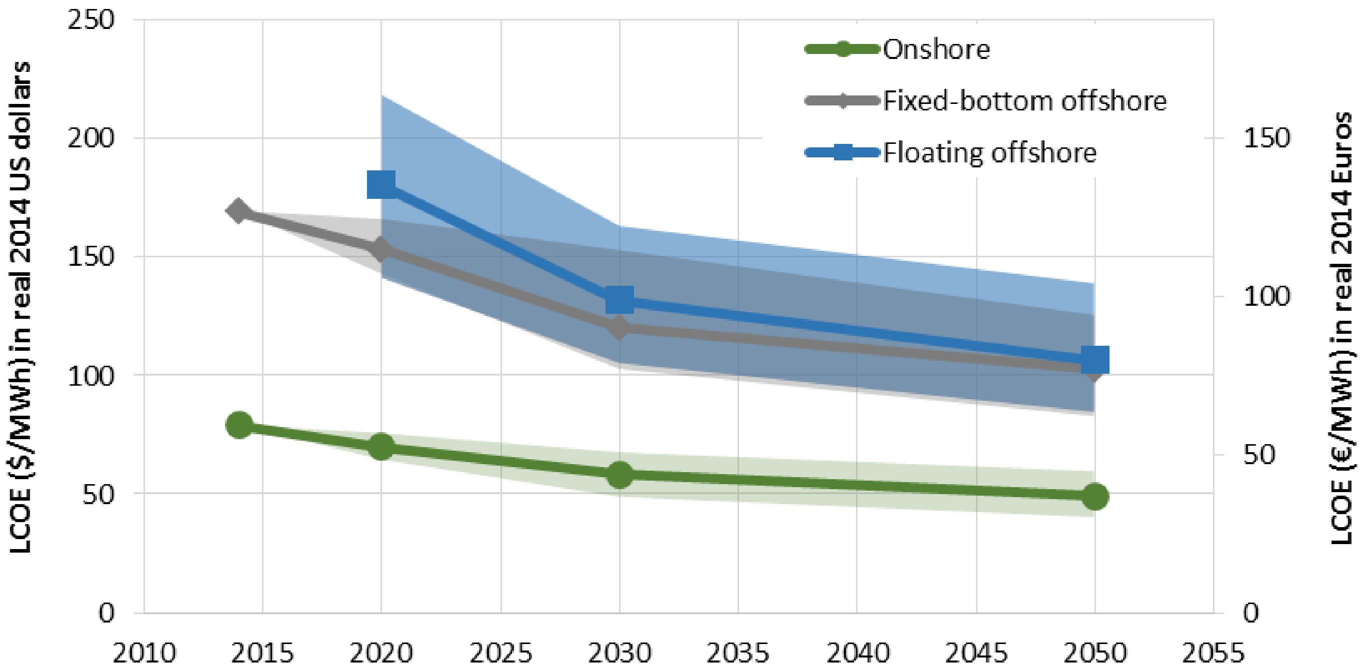
Change is shown relative to baseline for fixed-bottom offshore as no 2014 baseline was established for floating offshore

Median LCOE in Median Scenario, 2014-2050: ***All Applications***

Narrowing range between LCOE of onshore and offshore wind: offshore wind LCOE declines faster in absolute terms

Similar narrowing between fixed-bottom and floating offshore wind, with sizable LCOE reductions for floating offshore wind between 2020 and 2030; but median respondent still estimates higher LCOE for floating to 2050

Far-greater uncertainty associated with offshore than onshore



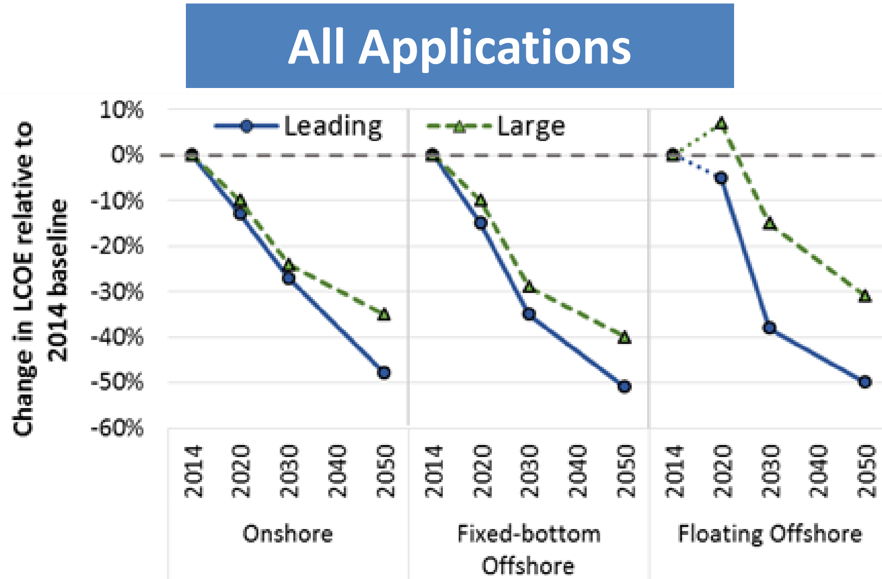
Lines/markers indicate the median expert response for the **median LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

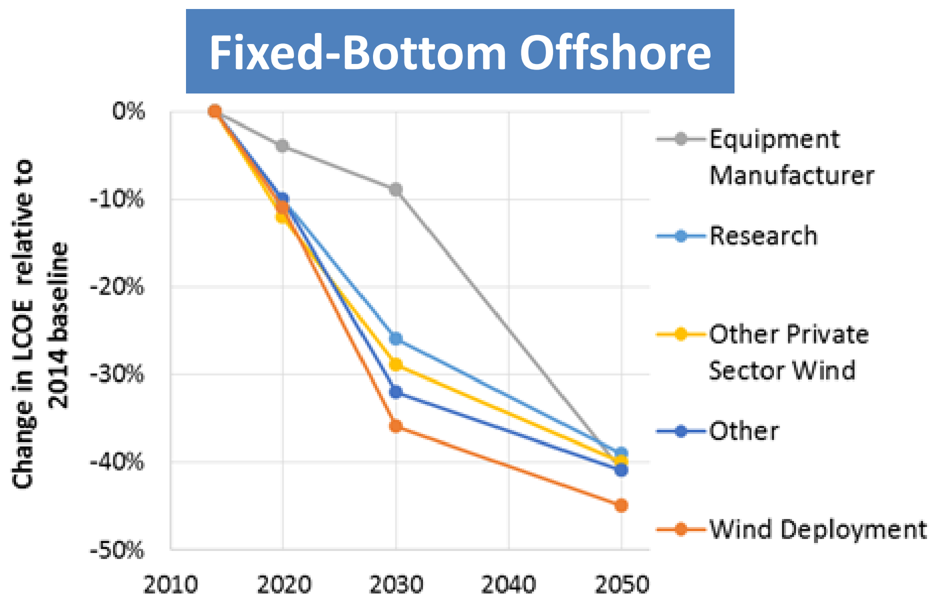
Note: Emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. Because the 2014 baselines shown in the figure are the median of expert responses, they do not represent any specific region of the world. For any specific region, the 2014 baselines and future absolute LCOE values would vary. Additionally, because roughly 80% of experts chose to use the default 2014 baseline values for onshore and fixed-bottom offshore, the 1st and 3rd quartile as well and the median expert response for 2014 are all equivalent to those default baseline values.

Note: Percentage changes from the baseline are the most broadly applicable approach to presenting findings (because each region and expert might have a different baseline value), but the relative absolute values of expert-specified LCOEs are also relevant

Median Scenario LCOE Reduction:
Differences Among Respondent Groups

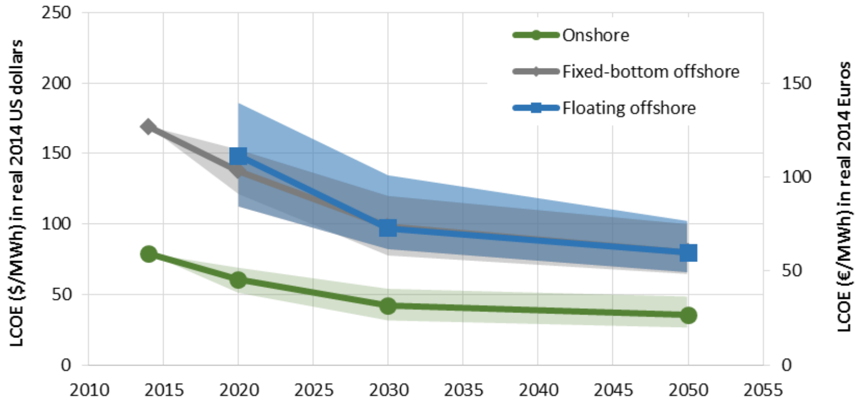
- Range in expert-specific responses can be partly explained by segmenting respondents into various categories
- Smaller “leading-expert” group generally more aggressive on LCOE reductions than larger set of respondents *less* that group
- Equipment manufacturers expect less reduction in 2020/2030 for fixed-bottom offshore, but converge in 2050; deployment group a bit more optimistic for fixed-bottom
- Respondents who only expressed knowledge of offshore wind tend to be more aggressive on LCOE reduction for offshore wind than those with expertise in both onshore and offshore applications
- Those who claim expertise on “markets/ cost analysis” generally more optimistic than those with technology expertise





Overall LCOE Reduction, 2014-2050: ***Fixed-Bottom versus Floating Offshore***

- In **median scenario**, the median-respondent LCOE of floating offshore wind is anticipated to remain slightly higher than that of fixed-bottom wind through 2050, but the gap narrows and is very small by 2050 (see slide 30); in the **low scenario**, the median respondent expects an earlier LCOE convergence (see slide to right)



Lines/markers indicate the median expert response for the **low LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

- Of those who answered for both fixed-bottom and floating offshore wind, under the **median scenario**, 23% see floating as less expensive than fixed-bottom in 2030, increasing to 40% in 2050

- The leading-expert group is more optimistic for the convergence between fixed-bottom and floating offshore than the larger group (less the leading experts):
  - **In median LCOE scenario** in 2050, leading experts predict median LCOE reduction of 51% for fixed-bottom and 50% for floating (see slide 31), whereas larger group predicts 40% reduction for fixed-bottom and 31% for floating
  - **In low LCOE scenario** in 2050, leading experts predict median LCOE reductions of 62% for fixed-bottom and 64% for floating, whereas larger respondent group expects 53% for fixed-bottom and 50% reductions for floating (see appendix slides)

- Note: comparisons exclude any differences in transmission connection to shore

2014 Baseline LCOE and LCOE Components: *Onshore and Fixed-Bottom Offshore Wind*

Respondents given parameters for typical US/European project for default 2014 baseline, which they could revise as desired

~80% of respondents accepted baselines

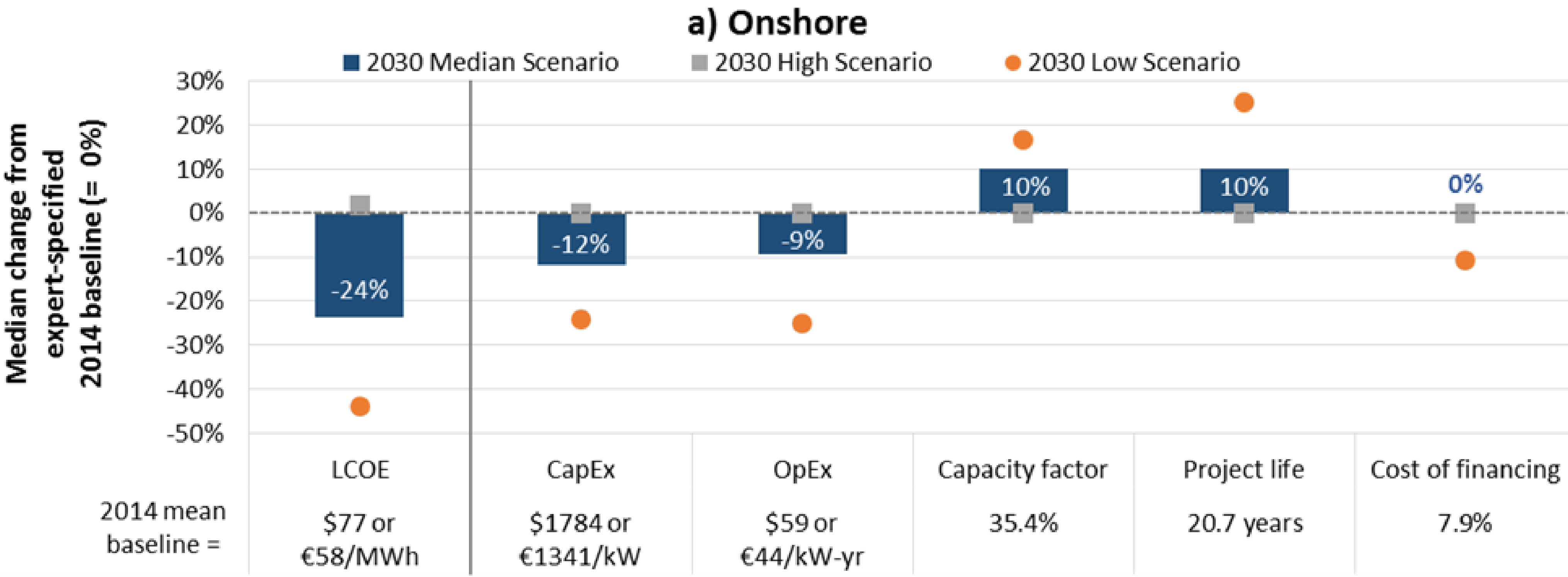
Those who revised onshore baseline tend towards lower LCOE based on U.S. projects, while those who revised offshore baseline tend towards higher LCOE

ONSHORE WIND	LCOE	Capital costs	Operating expenses	Capacity factor	Project design life	Cost of financing
Default baseline values (also the median response of all experts)	$79/MWh €59/MWh	$1,800/kW €1,353/kW	$60/kW-yr €45/kW-yr	35%	20 years	8%
Mean baseline value across all experts	$77/MWh €58/MWh	$1,784/kW €1,341/kW	$59/kW-yr €44/kW-yr	35%	20.7 years	7.9%
Responding experts who defined their own baseline values (of 134 total respondents)	23%	21%	20%	19%	13%	14%
Median for respondents changing the baseline LCOE	$64/MWh €48/MWh	$1,650/kW €1,241/kW	$55/kW-yr €41/kW-yr	36%	25 years	8%
% of self-defined values indicative of a lower LCOE than the default values	71%	71%	74%	52%	52%	45%

FIXED-BOTTOM OFFSHORE WIND	LCOE	Capital costs	Operating expenses	Capacity factor	Project design life	Cost of financing
Default baseline values (also the median response of all experts)	$169/MWh €127/MWh	$4,600/kW €3,459/kW	$110/kW-yr €83/kW-yr	45%	20 years	10%
Mean baseline values across all experts	$171/MWh €129/MWh	$4,646/kW €3,493/kW	$115/kW-yr €86/kW-yr	45%	20.3 years	10%
Responding experts who defined their own baseline values (of 110 total respondents)	20%	19%	18%	12%	7%	5%
Median for respondents changing the baseline LCOE	$189/MWh €142/MWh	$4,600/kW €3,459/kW	$123/kW-yr €93/kW-yr	45%	20 years	10%
% of self-defined values indicative of a lower LCOE than the default values	23%	32%	14%	14%	36%	14%

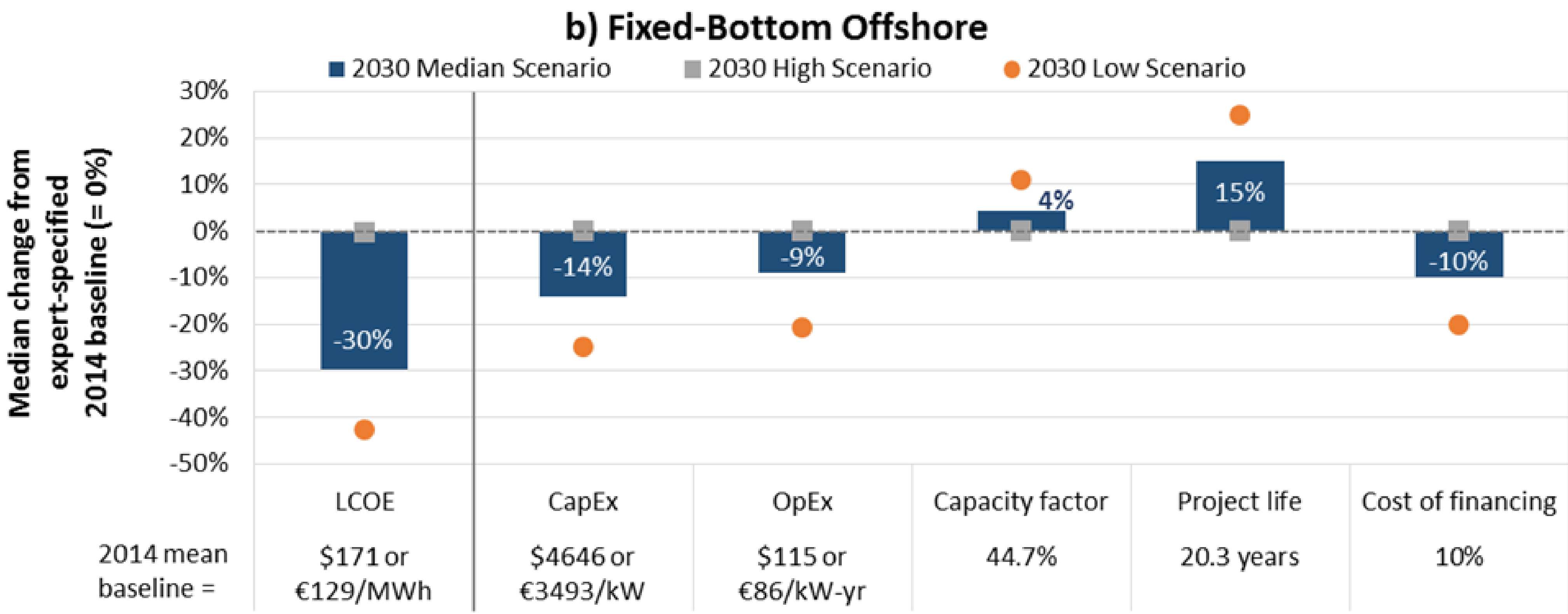
Relative Change in LCOE Components: *Onshore Wind, 2014-2030*

Component-specific changes from 2014-2030 depend on low, median, high scenario; median respondent in median scenario: CapEx: -12%; OpEx: -9%; capacity factor: +10%; project life: +10%; cost of finance: no Δ



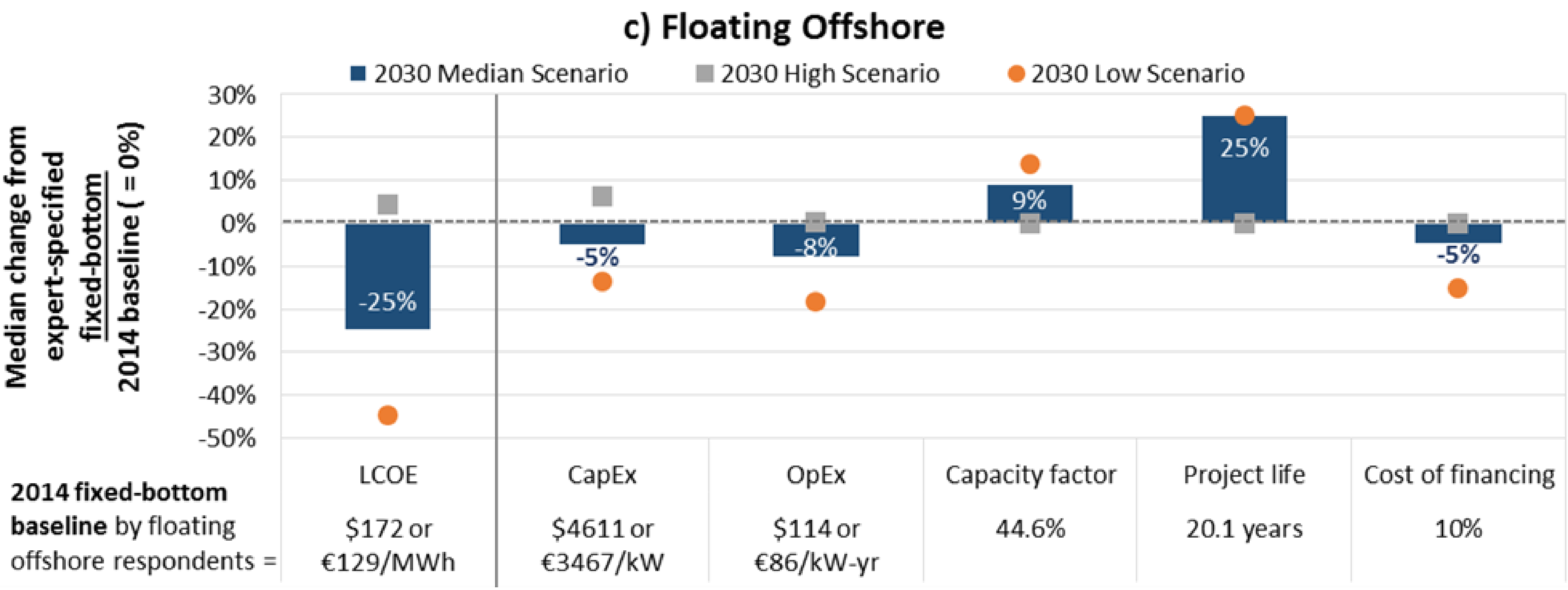
Relative Change in LCOE Components: *Fixed-Bottom Offshore Wind, 2014-2030*

Component-specific changes from 2014-2030 depend on low, median, high scenario; median respondent in <u>median scenario</u>: CapEx: -14%; OpEx: -9%; capacity factor: +4%; project life: +15%; cost of finance: -10%



Relative Change in LCOE Components: *Floating Offshore Wind, 2014-2030*

Component-specific changes from 2014-2030 depend on low, median, high scenario; median respondent in median scenario: CapEx: -5%; OpEx: -8%; capacity factor: +9%; project life: +25%; cost of finance: -5%

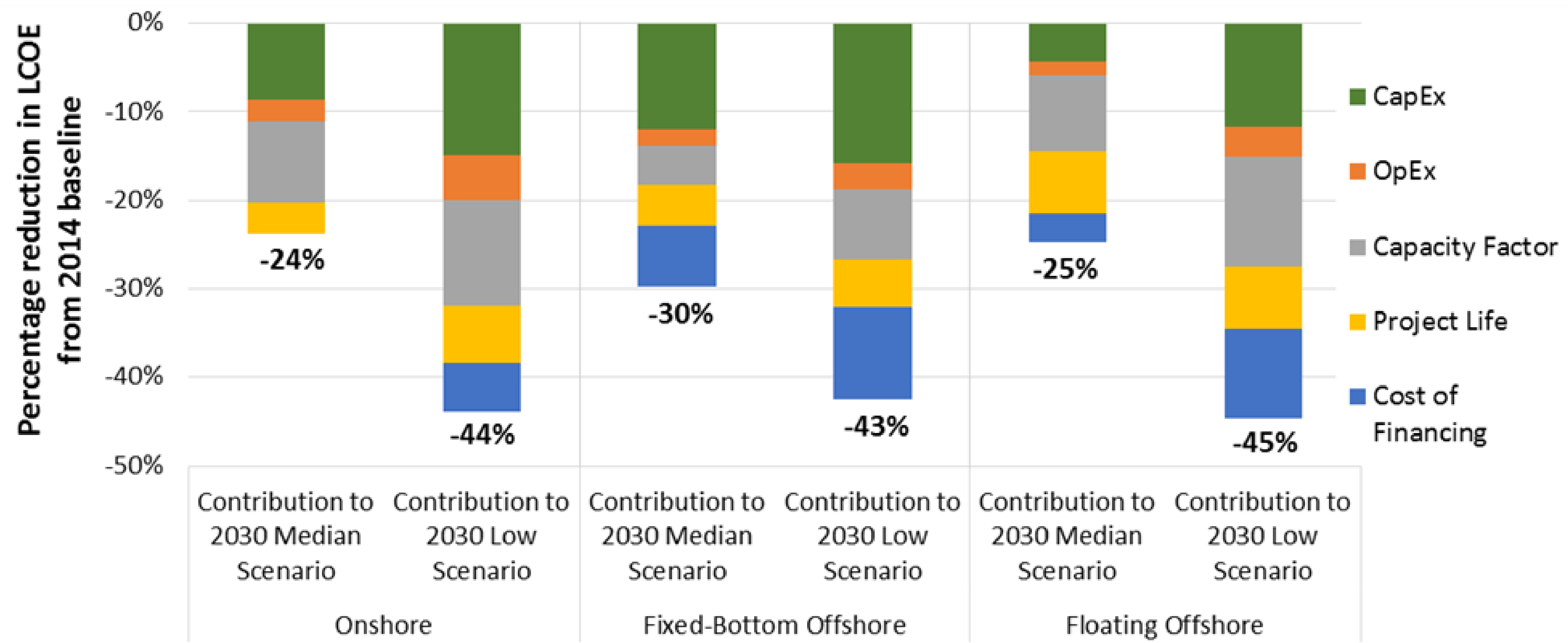


Scaled Impact of Components on LCOE: *All Applications, 2014-2030*

Onshore LCOE reductions in median and low scenarios driven by CapEx and capacity factor, with lesser impact from project life, OpEx, cost of financing

Fixed-bottom offshore LCOE reductions in median and low scenarios driven by CapEx, then cost of financing, then capacity factor, project life, and OpEx

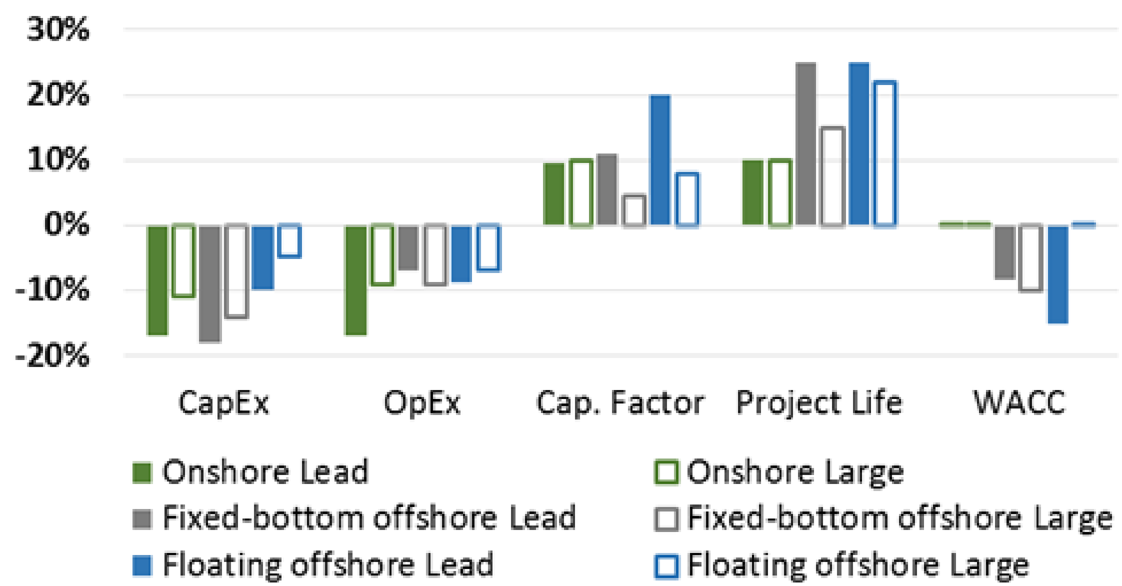
Relative to fixed-bottom, **floating offshore** LCOE reductions driven more by capacity factor, less by CapEx



Relative Change in LCOE Components: ***Differences Among Respondent Groups***

- Leading experts have greater CapEx and OpEx improvements for **onshore wind**; CapEx, capacity factor, design life for **fixed-bottom offshore**; CapEx, OpEx, capacity factor, cost of finance for **floating offshore**
- Equipment manufacturers often more cautious about improvements, for both onshore and offshore
- Respondents who only express knowledge of offshore expect greater improvements for most factors, and especially cost of finance, but are less optimistic on CapEx reductions

Sources of LCOE Reduction in 2030 Median Scenario: Leading-Expert Group vs. Larger Group



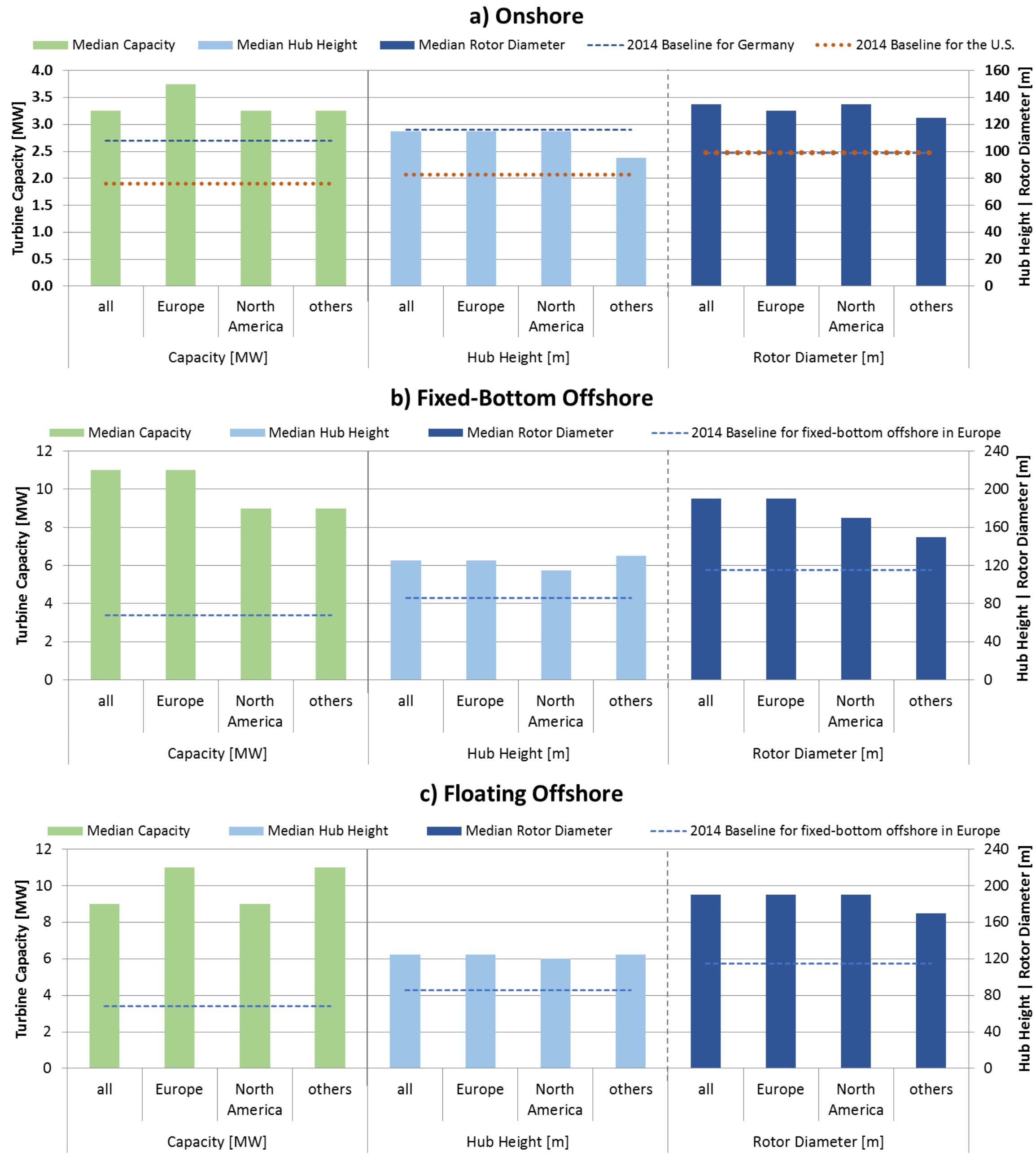
Turbine Characteristics, Typical in 2030: ***All Applications***

Nameplate capacity ratings increase, especially offshore; higher capacity ratings for onshore and offshore in Europe than in North America

Onshore hub height reaches current average in Germany by 2030, similar in Europe and North America; hub heights increase offshore as well

Rotor diameters increase from current averages onshore and offshore, across all regions

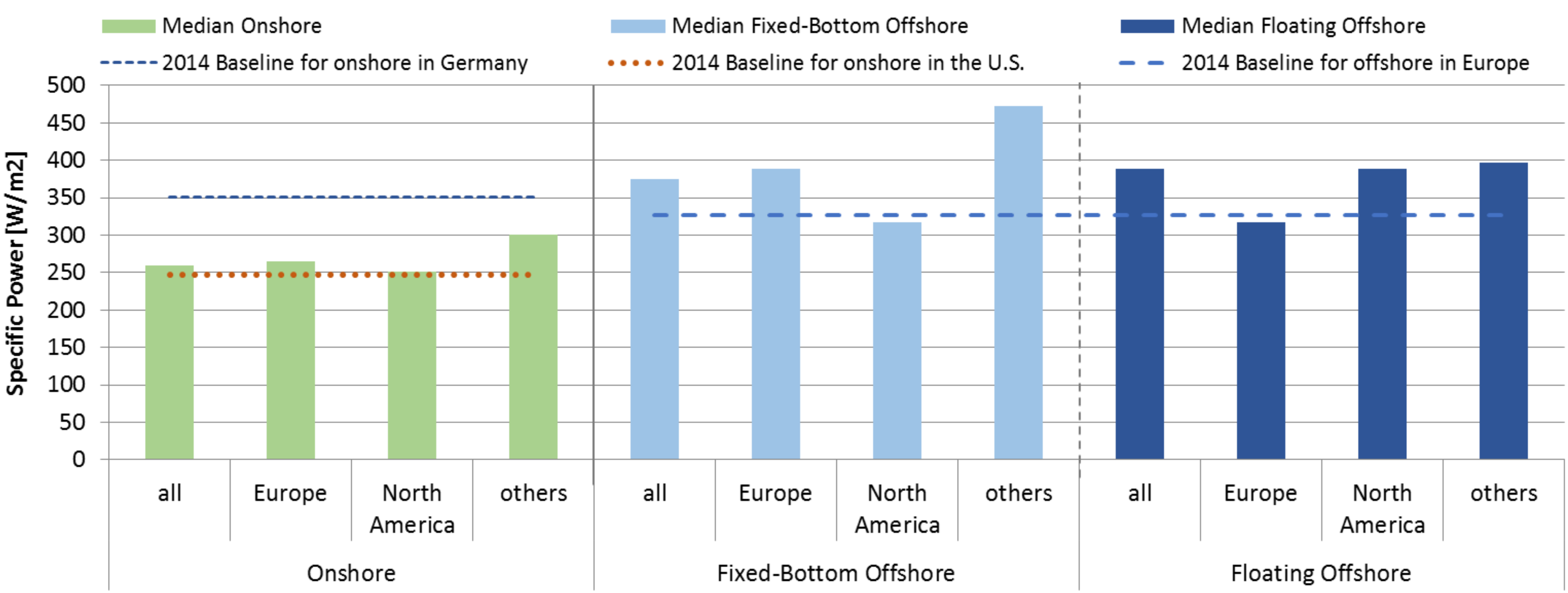
No major differences of note among respondent groups (see appendix slides)



Turbine Specific Power, Typical in 2030: ***All Applications***

Onshore, specific power anticipated to stay at current levels in North America, and to decline to North American levels in Europe, by 2030

Offshore, specific power remains at current European levels → emphasis on growing machine ratings and scaling rotors proportionately; specific power higher offshore than onshore



Relative Impact on LCOE Reductions in 2030: ***All Applications, Summary***

Survey asked about expected impact (4-point scale) of 28 different wind technology, market, and other changes on LCOE reductions by 2030, separately for onshore, fixed-bottom offshore, and floating offshore wind; results broadly consistent with earlier survey findings

Onshore: rotor-related advancements viewed as especially important

Fixed-bottom offshore: upscaling, foundations, lower financing costs

Floating offshore: support structures, more efficient installation processes

See appendix slides for differences among respondent groups

Relative Impact on LCOE Reductions in 2030: *Onshore, Land-Based Wind*

Largest drivers included:

- Larger rotors, reduced specific power
- Rotor design advancements

Others below that included:

- Taller towers
- Reduced financing costs
- Component durability/reliability
- New transmission
- Extended turbine design lifetime
- Operating efficiencies / ↑ performance
- Larger turbine capacity ratings
- Turbine / component manufacturing
- Improved plant-level layout
- Integrated turbine-level design

	Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact
Onshore Wind	Increased rotor diameter such that specific power declines	58%	2.5
	Rotor design advancements	45%	2.3
	Increased tower height	33%	2.2
	Reduced financing costs and project contingencies	32%	2.1
	Improved component durability and reliability	31%	2.1
	Increased energy production due to new transmission to higher wind speed sites	31%	2.0
	Extended turbine design lifetime	29%	2.0
	Operating efficiencies to increase plant performance	28%	2.0
	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	1.9
	Turbine and component manufacturing standardization, efficiencies, and volume	27%	2.0
	Improved plant layout via understanding of complex flow and high-resolution micro-siting	27%	2.0
	Integrated turbine-level system design optimization	23%	2.0
Fixed-Bottom Offshore Wind	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	2.4
	Foundation and support structure design advancements	53%	2.4
	Reduced financing costs and project contingencies	49%	2.4
	Economies of scale through increased project size	48%	2.3
	Improved component durability and reliability	48%	2.3
	Installation process efficiencies	46%	2.4
	Installation and transportation equipment advancements	44%	2.3
	Foundation/support structure manufacturing standardization, efficiencies, and volume	43%	2.2
	Extended turbine design lifetime	36%	2.2
	Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1
	Increased competition among suppliers	35%	2.1
	Integrated turbine-level system design optimization	33%	2.1
Floating Offshore Wind	Foundation and support structure design advancements	80%	2.8
	Installation process efficiencies	78%	2.7
	Foundation/support structure manufacturing standardization, efficiencies, and volume	68%	2.6
	Economies of scale through increased project size	65%	2.6
	Installation and transportation equipment advancements	63%	2.5
	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	2.4
	Improved component durability and reliability	58%	2.5
	Reduced financing costs and project contingencies	46%	2.3
	Increased competition among suppliers	46%	2.2
	Rotor design advancements	45%	2.1
	Integrated turbine-level system design optimization	44%	2.3
	Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3

Relative Impact on LCOE Reductions in 2030

Fixed-Bottom Offshore Wind

BERKELEY LAB

A lot of things matter!

Largest drivers included:

- Larger turbine capacity ratings
- Foundation/support structure design
- Reduced financing costs
- Economies of scale via project size
- Component durability/reliability
- Installation process efficiencies
- Installation / transport equipment
- Foundation/support manufacturing

Others below that included:

- Extended turbine design lifetime
- Turbine / component manufacturing
- Increased competition among suppliers
- And many more with similar ratings…

	Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating, Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Onshore Wind	Increased rotor diameter such that specific power declines	58%	2.5	
	Rotor design advancements	45%	2.3	
	Increased tower height	33%	2.2	
	Reduced financing costs and project contingencies	32%	2.1	
	Improved component durability and reliability	31%	2.1	
	Increased energy production due to new transmission to higher wind speed sites	31%	2.0	
	Extended turbine design lifetime	29%	2.0	
	Operating efficiencies to increase plant performance	28%	2.0	
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	Turbine and component manufacturing standardization, efficiencies, and volume	27%	2.0	
	Improved plant layout via understanding of complex flow and high-resolution micro-siting	27%	2.0	
	Integrated turbine-level system design optimization	[illegible]	[illegible]	
Fixed-Bottom Offshore Wind	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	2.4	
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	Improved component durability and reliability	48%	2.3	
	Installation process efficiencies	46%	2.4	
	Installation and transportation equipment advancements	44%	2.3	
	Foundation/support structure manufacturing standardization, efficiencies, and volume	43%	2.2	
	Extended turbine design lifetime	36%	2.2	
	Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1	
	Increased competition among suppliers	35%	2.1	
	Integrated turbine-level system design optimization	33%	2.1	
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	Installation process efficiencies	78%	2.7	
	Foundation/support structure manufacturing standardization, efficiencies, and volume	68%	2.6	
	Economies of scale through increased project size	65%	2.6	
	Installation and transportation equipment advancements	63%	2.5	
	Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	2.4	
	Improved component durability and reliability	58%	2.5	
	Reduced financing costs and project contingencies	46%	2.3	
	Increased competition among suppliers	46%	2.2	
	Rotor design advancements	45%	2.1	
	Integrated turbine-level system design optimization	44%	2.3	
	Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3	

Relative Impact on LCOE Reductions in 2030
Floating Offshore Wind

Many similar themes to fixed-bottom; even greater emphasis on support structure and installation

Largest drivers included:

- Foundation/support structure design
- Installation process efficiencies
- Foundation/support manufacturing
- Economies of scale via project size
- Installation / transport equipment
- Larger turbine capacity ratings
- Component durability/reliability

Others below that included:

- Reduced financing costs
- Increased competition among suppliers
- Rotor design advancements
- Integrated turbine-level design
- Turbine / component manufacturing

	Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating, Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact
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	Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1
	Increased competition among suppliers	35%	2.1
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	Increased competition among suppliers	46%	2.2
	Rotor design advancements	45%	2.1
	Integrated turbine-level system design optimization	44%	2.3
	Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3

Ranking of Broad Drivers to Achieve Low LCOE in 2030: Onshore and Fixed-Bottom Offshore

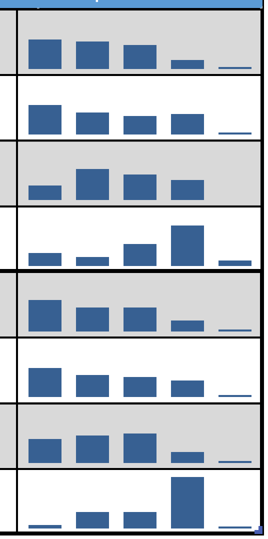
Asked respondents to rank broad drivers that might enable achieving low-scenario LCOE, separately for onshore and fixed-bottom offshore

“Learning with market growth” was deemed to be the highest rated item for both onshore and offshore, followed closely by “research and development”

“Increased competition and decreased risk” was the third-ranked item for onshore, while “eased project and transmission siting” was for offshore

See appendix slides for differences among respondent groups

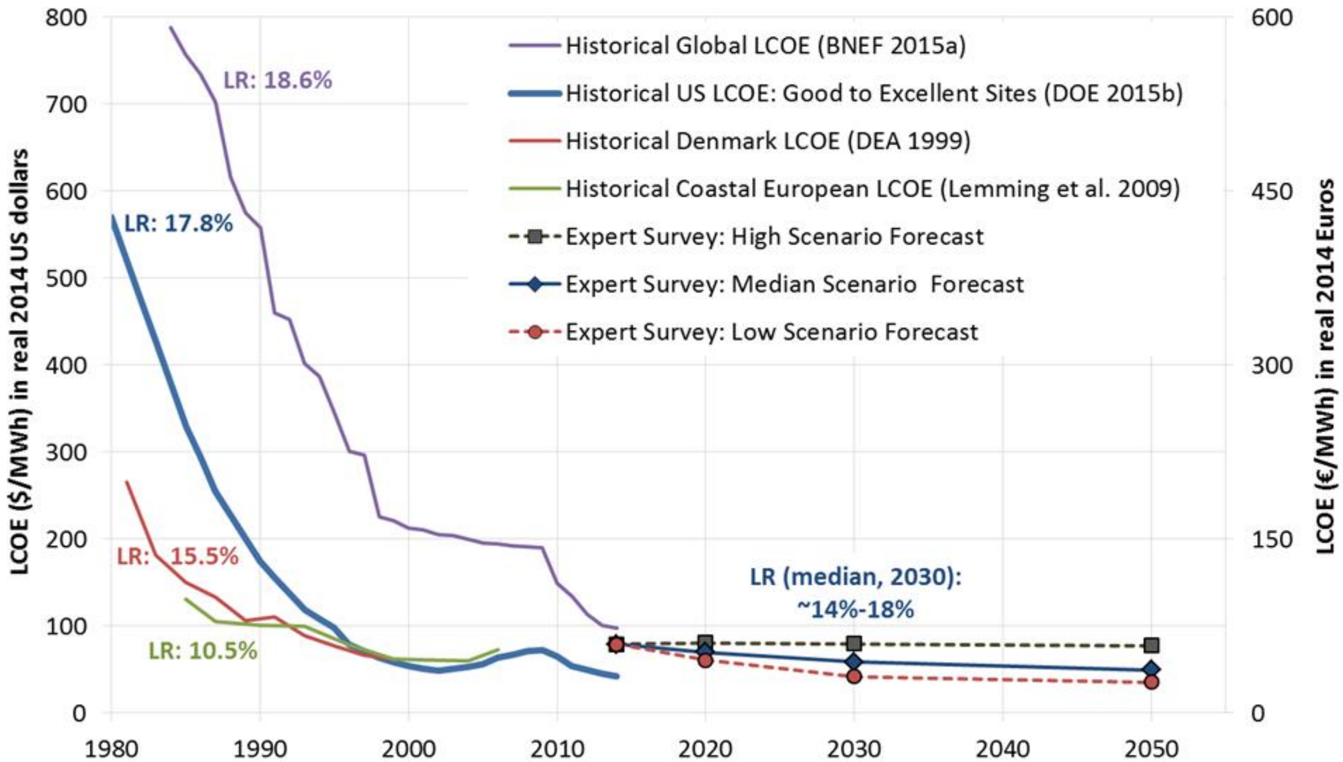
	Wind technology, market, or other change	Percentage of experts ranking item "most important"	Mean Rating, Rating Distribution Ranking from **1**- most important to 5- least important	
Onshore Wind	Learning with market growth	33%	2.2	
	Research & development	32%	2.4	
	Increased competition & decreased risk	16%	2.5	
	Eased wind project & transmission siting	14%	3.2	
Offshore Wind	Learning with market growth	33%	2.2	
	Research & development	32%	2.3	
	Eased wind project & transmission siting	25%	2.3	
	Increased competition & decreased risk	5%	3.4	



Comparison of LCOE Survey Results to Historical LCOE and Related Learning Rates

Historical LCOE-based learning estimates for **onshore wind** show a 10.5% to 18.6% reduction in LCOE for each doubling of cumulative global wind capacity

Survey results for median scenario are fully consistent with this range, at ~14% to 18%; survey results for low scenario show higher learning than historical trends



Note: For the expert survey results, emphasis should be placed on the relative positioning of and changes in LCOE, not on absolute magnitudes. Because the 2014 baselines shown in the figure are the median of expert responses, they do not represent any specific region of the world. For any specific region, the 2014 baselines and future absolute LCOE values would vary. For similar reasons, it is not appropriate to compare expert-survey results in terms of absolute LCOE magnitudes with the historical LCOE estimates shown on the chart for specific regions. Finally, learning rates are calculated based on a log-log relationship between LCOE and cumulative wind installations; as such, while historical learning rates closely match expected future learning predicted by the expert elicitation, visual inspection of the figure does not immediately convey that result.

Limited historical data for **offshore**, not much evidence for LCOE reductions so far

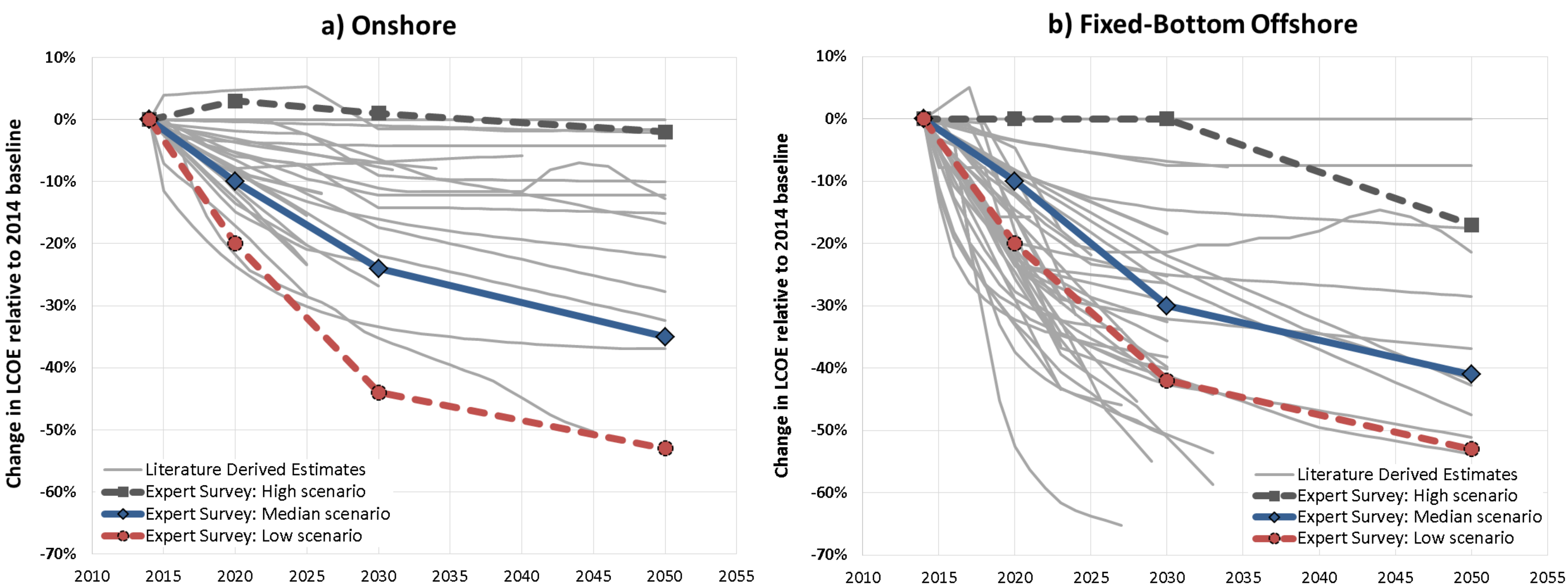
Implicit survey-based learning for **fixed-bottom offshore**, based on 2030 cumulative offshore wind capacity:

- 8% (median scenario)
- 13% (low scenario)

Findings suggest that experts either anticipate lower offshore-only learning (relative to onshore) or expect learning spillovers from on- to off-shore

Comparison of LCOE Survey Results to Other Forecasts: ***Onshore and Offshore Wind***

Expert survey results for onshore and fixed-bottom offshore wind are broadly within the range of other estimates of future LCOE reduction, however: (1) median-scenario survey-based LCOE trajectory for onshore wind tends somewhat towards lower end of literature range; and (2) survey results for fixed-bottom offshore wind in median- and low-scenarios are more-conservative than much of the broader literature

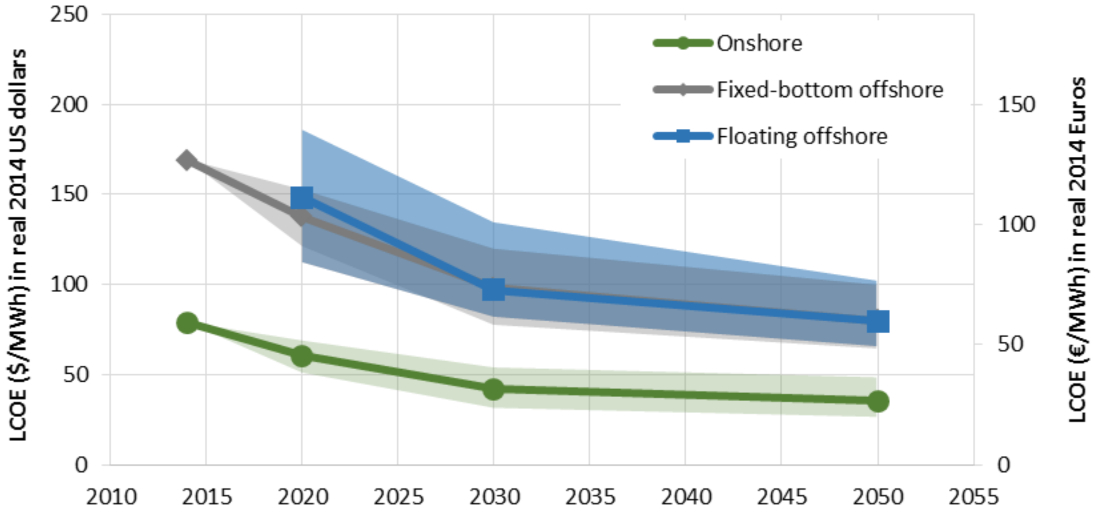


Applying Learning Rates to Forecast Future Wind Energy Costs: Getting it Right

- Learning rate estimates for onshore wind range widely, from 33% to -11%, due to differences in model specification, geographic scope, analysis period
- Multiple concerns associated with using historical data to construct learning rates that are then used to forecast future costs; nonetheless, this is common practice
- Previous onshore wind LCOE learning comparison suggests that properly constructed learning rates may be reasonably used to forecast future costs for more mature applications (not obviously true for offshore wind)
  - Elicitation results for onshore wind are consistent with historical learning rates
- However, majority of literature focuses on CapEx-based learning, with recently-estimated long-term onshore CapEx learning rates of 6%-9%
  - Well below historical LCOE learning (10.5-18.6%) and survey findings (14-18%)
  - Survey shows CapEx improvements to be only one means of achieving lower LCOE
- Use of CapEx-based learning may explain relative conservatism of other forecasts shown on previous slide; may result in understatement of cost reduction potential
- If used to forecast future costs, LCOE-based learning rates should be applied

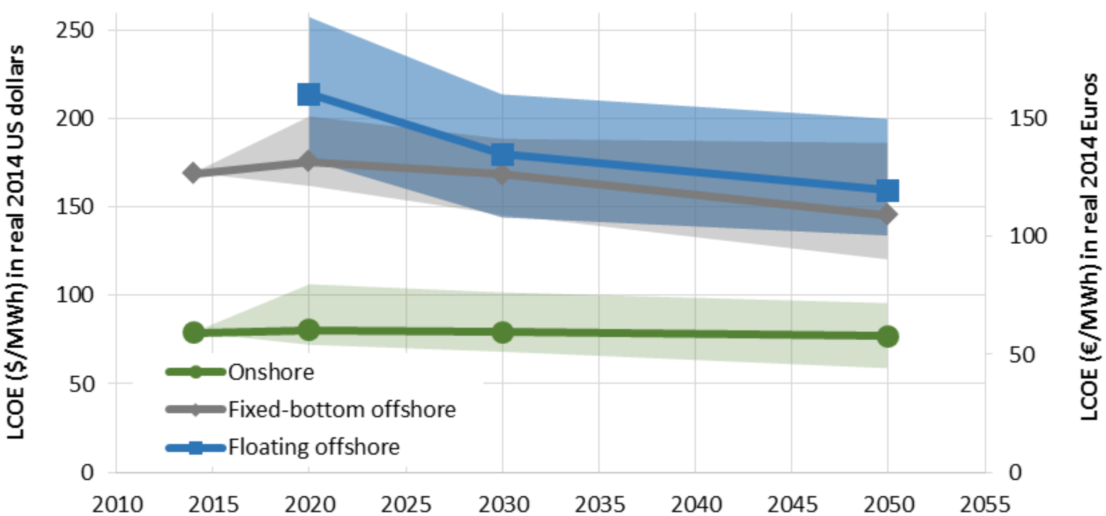
Appendix

Absolute LCOE, Low & High Scenarios:
All Applications, 2014 to 2050



Lines/markers indicate the median expert response for the **low LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

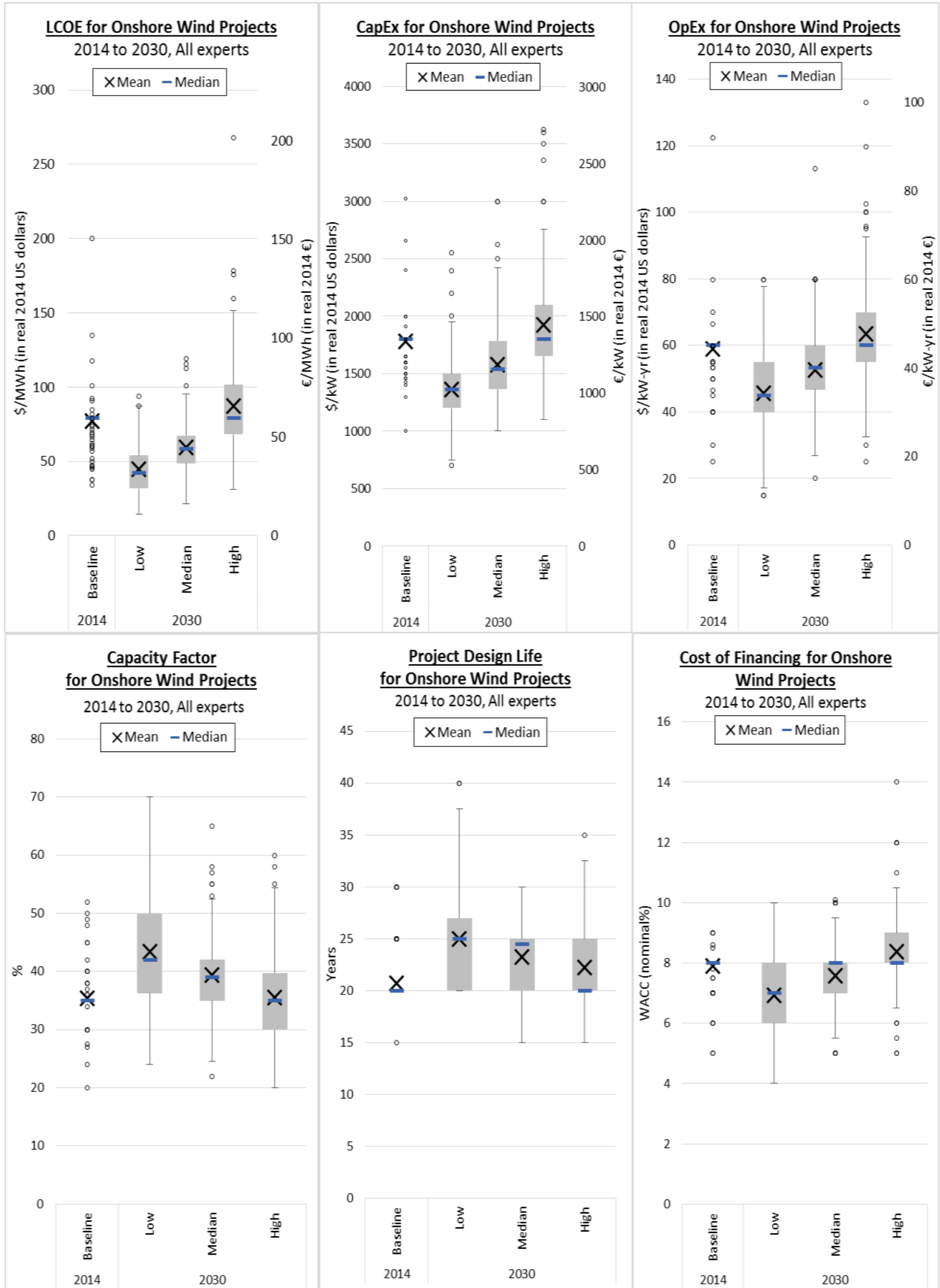
LOW SCENARIO



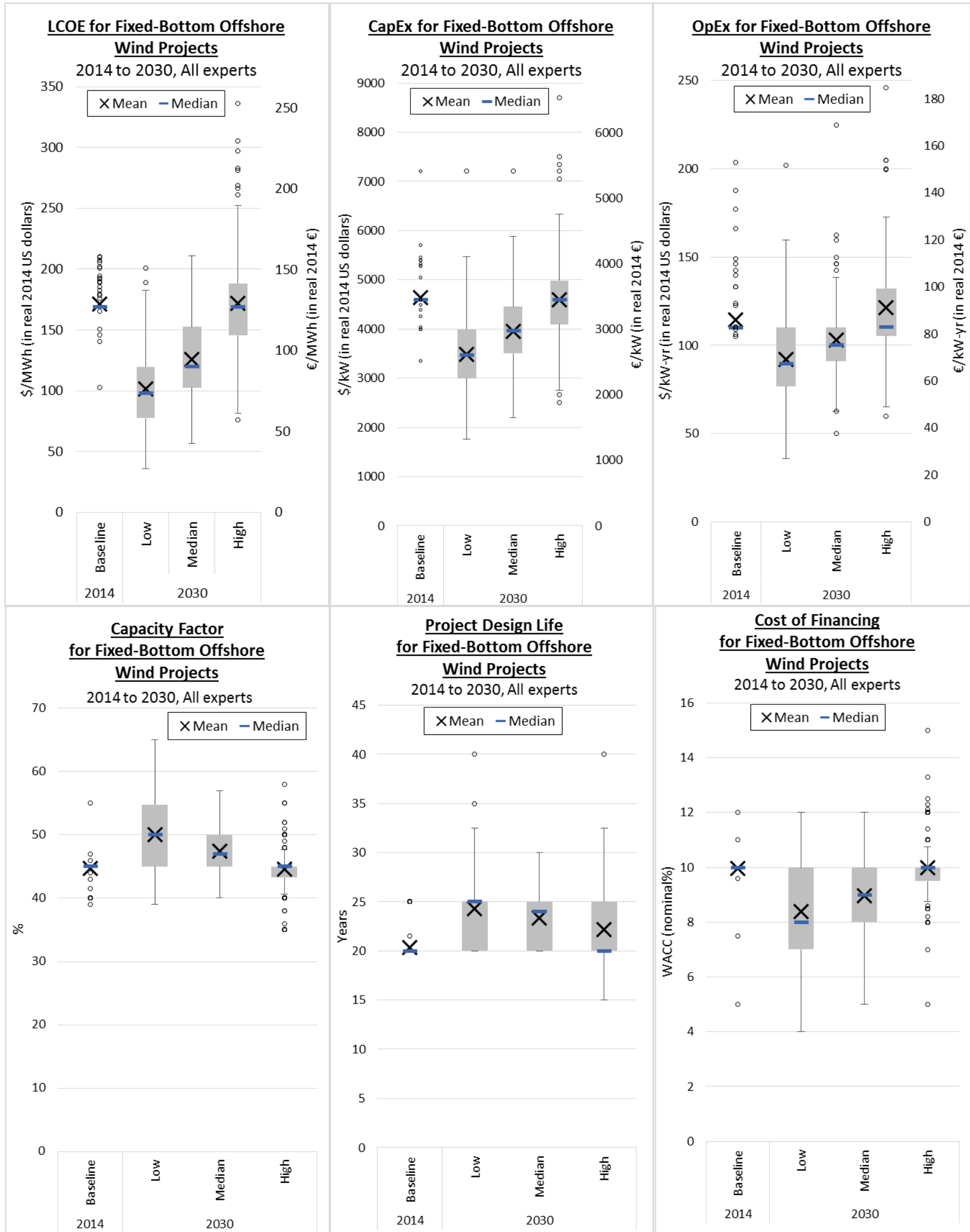
Lines/markers indicate the median expert response for the **high LCOE scenario**
Shaded areas show the 1st-3rd quartiles of expert responses

HIGH SCENARIO

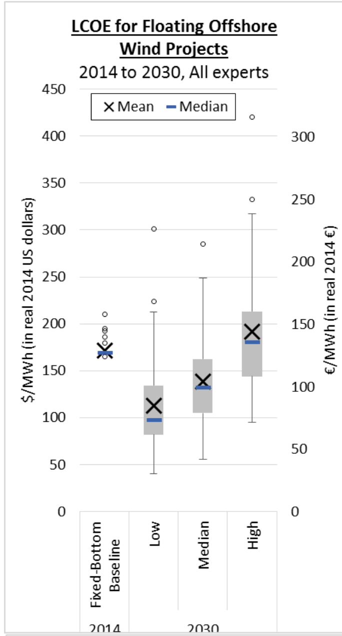
Changes in LCOE and LCOE Components: *Onshore Wind, 2014 to 2030*

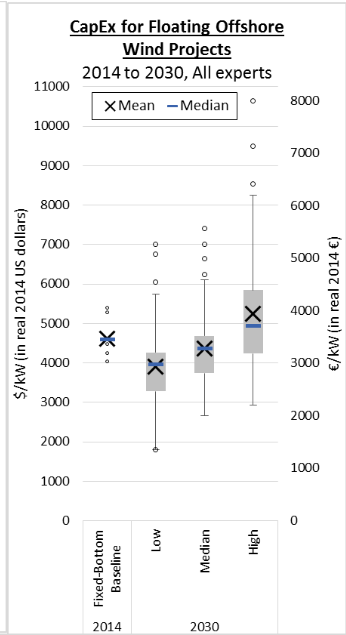


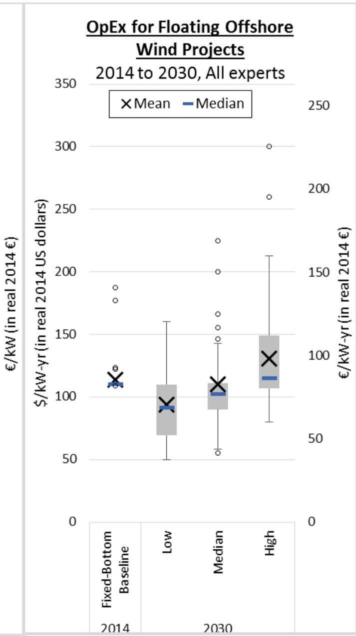
Changes in LCOE and LCOE Components:
Fixed-Bottom Offshore Wind, 2014 to 2030

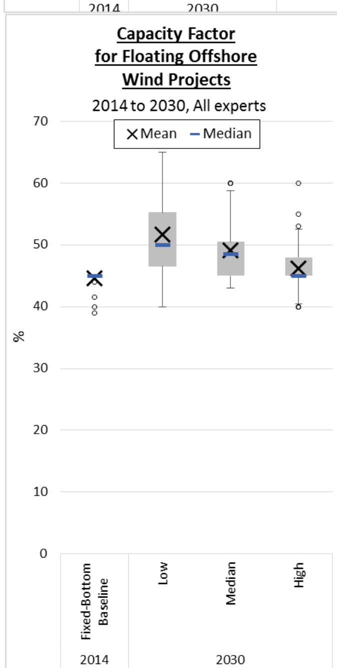


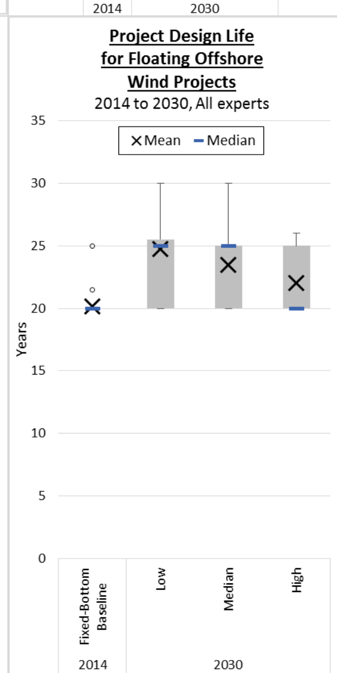
Changes in LCOE and LCOE Components: *Floating Offshore Wind, 2014 to 2030*

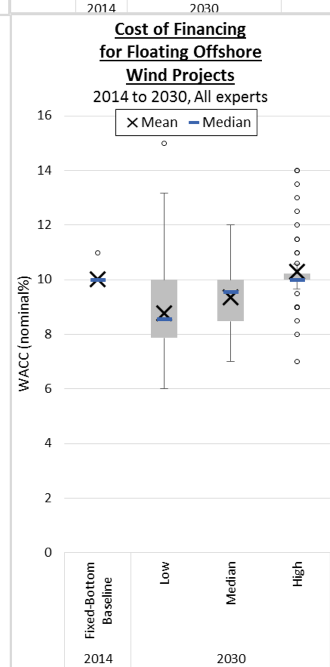




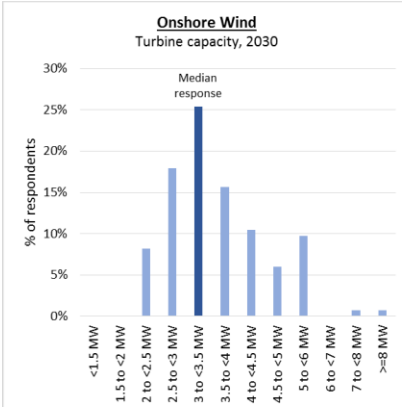


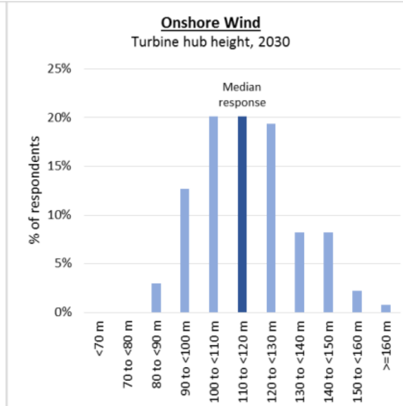


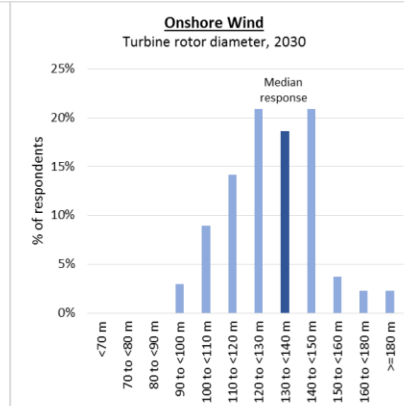


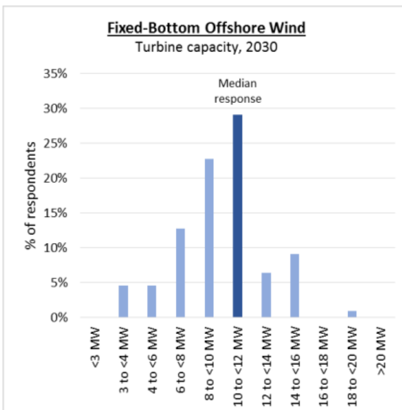


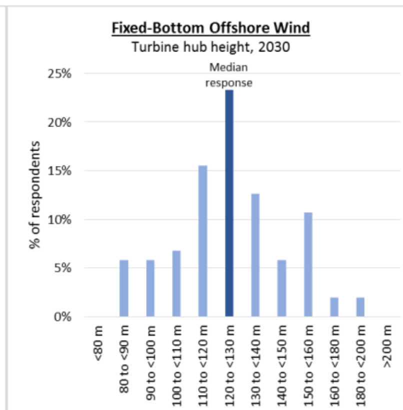
Turbine Characteristics, typical in 2030: ***All Applications***

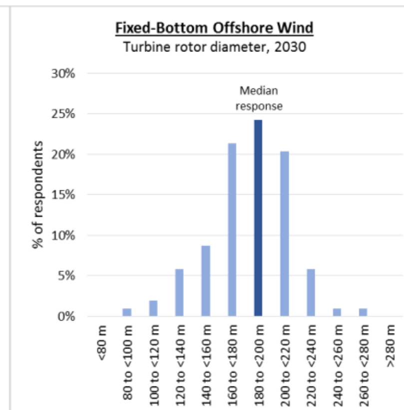


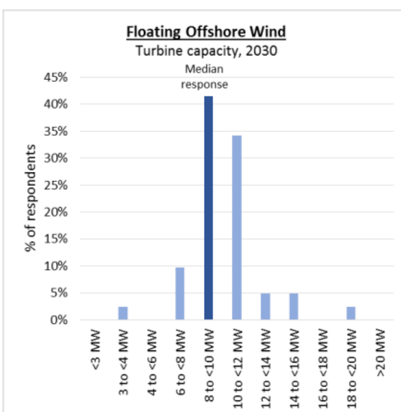


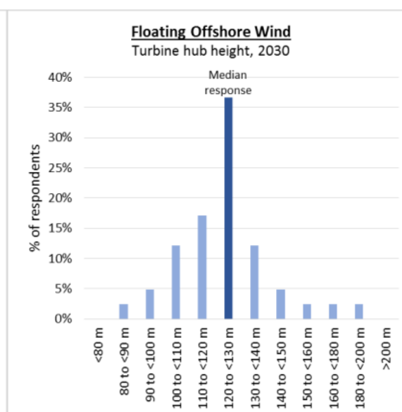


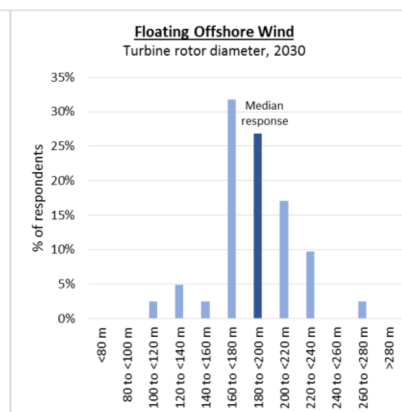




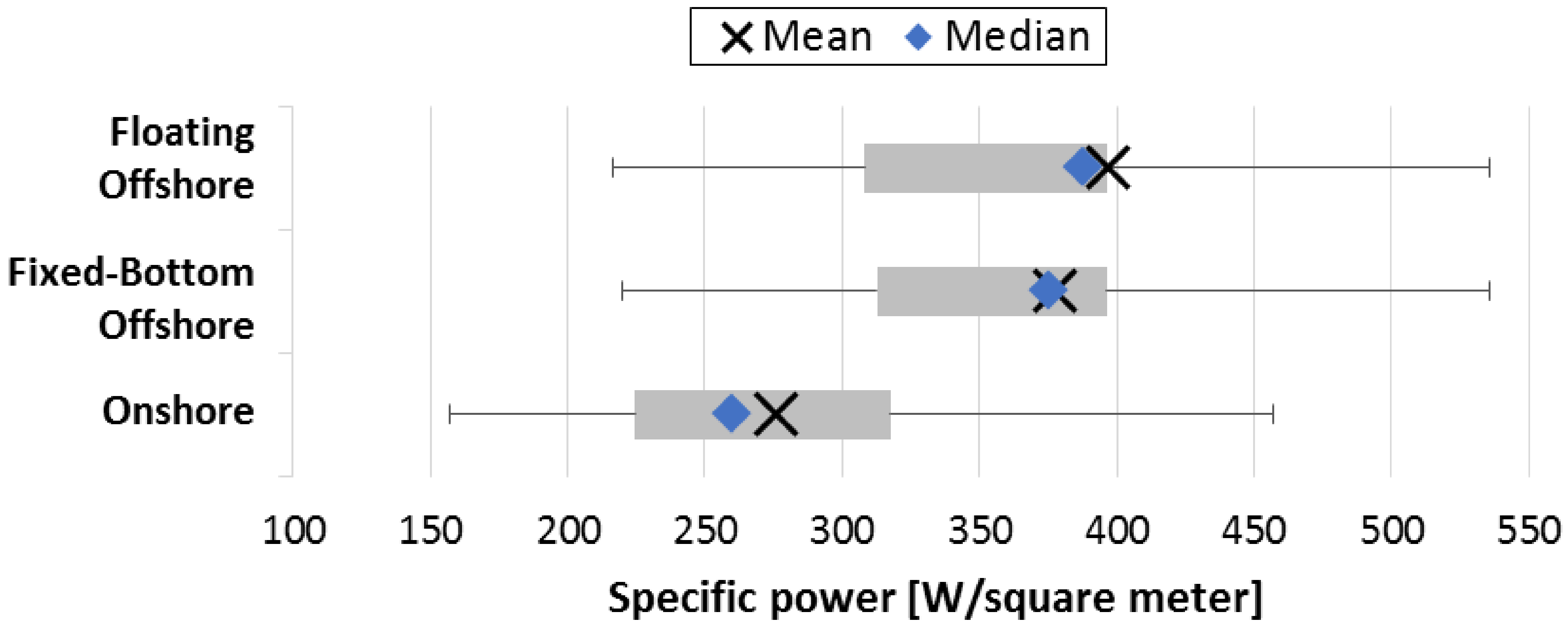








Turbine Specific Power, typical in 2030: ***All Applications***



Relative Impact on LCOE Reductions in 2030: ***Onshore, Land-Based Wind***

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact	
Increased rotor diameter such that specific power declines	58%	2.5	
Rotor design advancements	45%	2.3	
Increased tower height	33%	2.2	
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	32%	2.1	
Improved component durability and reliability	31%	2.1	
Increased energy production due to new transmission to higher wind speed sites	31%	2.0	
Extended turbine design lifetime	29%	2.0	
Operating efficiencies to increase plant performance	28%	2.0	
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	1.9	
Turbine and component manufacturing standardization, efficiencies, and volume	27%	2.0	
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	27%	2.0	
Integrated turbine-level system design optimization	23%	2.0	
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	21%	1.8	
Large variety of alternative turbine designs to suit site-specific conditions	17%	1.7	
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	17%	1.6	
Maintenance process efficiencies	17%	1.8	
Tower design advancements	14%	1.8	
Economies of scale through increased project size	12%	1.6	
Installation and transportation equipment advancements	12%	1.7	
Nacelle components design advancements	12%	1.6	
Innovative non-conventional turbine designs	12%	1.2	
Maintenance equipment advancements	10%	1.6	
Foundation and support structure manufacturing standardization, efficiencies, and volume	10%	1.5	
Foundation and support structure design advancements	10%	1.3	
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	9%	1.5	
Installation process efficiencies	9%	1.4	
Reduced fixed operating costs, excluding maintenance	5%	1.3	
Lower decommissioning costs	1%	0.8	

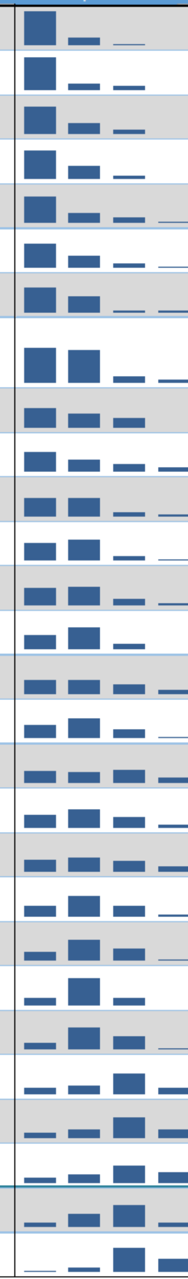
Relative Impact on LCOE Reductions in 2030

Fixed-Bottom Offshore Wind

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	2.4
Foundation and support structure design advancements	53%	2.4
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	49%	2.4
Economies of scale through increased project size	48%	2.3
Improved component durability and reliability	48%	2.3
Installation process efficiencies	46%	2.4
Installation and transportation equipment advancements	44%	2.3
Foundation and support structure manufacturing standardization, efficiencies, and volume	43%	2.2
Extended turbine design lifetime	36%	2.2
Turbine and component manufacturing standardization, efficiencies, and volume	36%	2.1
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	35%	2.1
Integrated turbine-level system design optimization	33%	2.1
Rotor design advancements	32%	2.1
Maintenance process efficiencies	32%	2.2
Maintenance equipment advancements	30%	2.0
Operating efficiencies to increase plant performance	29%	2.1
Increased rotor diameter such that specific power declines	27%	2.0
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	25%	1.9
Increased energy production due to new transmission to higher wind speed sites	21%	1.7
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	21%	1.8
Nacelle components design advancements	19%	1.9
Innovative non-conventional turbine designs	17%	1.5
Tower design advancements	12%	1.5
Reduced fixed operating costs, excluding maintenance	10%	1.5
Increased tower height	6%	1.3
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	5%	1.1
Large variety of alternative turbine designs to suit site-specific conditions	5%	1.2
Lower decommissioning costs	2%	0.9

Relative Impact on LCOE Reductions in 2030
Floating Offshore Wind

Wind technology, market, or other change	Percentage of experts rating item "Large expected impact"	Mean Rating , Rating Distribution 3- large impact 2- median impact 1- small impact 0- no impact
Foundation and support structure design advancements	80%	2.8
Installation process efficiencies	78%	2.7
Foundation and support structure manufacturing standardization, efficiencies, and volume	68%	2.6
Economies of scale through increased project size	65%	2.6
Installation and transportation equipment advancements	63%	2.5
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	2.4
Improved component durability and reliability	58%	2.5
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	46%	2.3
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	46%	2.2
Rotor design advancements	45%	2.1
Integrated turbine-level system design optimization	44%	2.3
Turbine and component manufacturing standardization, efficiencies, and volume	40%	2.3
Extended turbine design lifetime	39%	2.2
Maintenance process efficiencies	35%	2.2
Innovative non-conventional turbine designs	34%	1.9
Increased rotor diameter such that specific power declines	32%	2.1
Increased energy production due to new transmission to higher wind speed sites	29%	1.7
Tower design advancements	28%	1.9
Nacelle components design advancements	28%	1.8
Maintenance equipment advancements	25%	2.0
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	20%	1.9
Operating efficiencies to increase plant performance	18%	2.0
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	15%	1.8
Increased tower height	15%	1.4
Large variety of alternative turbine designs to suit site-specific conditions	12%	1.2
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	12%	1.2
Reduced fixed operating costs, excluding maintenance	8%	1.4
Lower decommissioning costs	3%	0.8



Changes in LCOE by Respondent Group: *Onshore Wind, 2014 to 2050*

BERKELEY LAB

Onshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		134	**-10%**	**-24%**	**-35%**	**-20%**	**-44%**	**-53%**	**3%**	**1%**	**-2%**
By Lead / Larger group	Leading	17	-13%	-27%	-48%	-26%	-57%	-66%	0%	0%	-7%
	Larger	117	-10%	-24%	-35%	-19%	-44%	-52%	3%	2%	-1%
By type of organization	Research	38	-9%	-25%	-31%	-21%	-44%	-50%	7%	10%	1%
	Wind deployment	22	-10%	-22%	-34%	-21%	-43%	-50%	0%	1%	-1%
	Equipment manufacturer	22	-12%	-23%	-36%	-21%	-40%	-53%	-3%	0%	-10%
	Other private sector	39	-10%	-26%	-37%	-18%	-48%	-54%	5%	7%	0%
	Other	13	-10%	-24%	-34%	-20%	-42%	-47%	0%	0%	-2%
By applications evaluated	Onshore only	52	-9%	-24%	-36%	-19%	-43%	-52%	4%	2%	3%
	Both onshore and offshore	82	-11%	-24%	-35%	-21%	-44%	-54%	3%	1%	-5%
By type of expertise	Wind energy markets	94	-10%	-27%	-38%	-21%	-46%	-54%	1%	0%	-2%
	Systems level	74	-11%	-26%	-38%	-21%	-44%	-53%	1%	0%	-6%
	Subsystem level	36	-8%	-24%	-34%	-21%	-44%	-53%	5%	0%	-4%
By familiarity with region	North American	93	-10%	-25%	-38%	-22%	-46%	-55%	2%	0%	-2%
	Europe	77	-10%	-23%	-32%	-21%	-44%	-53%	5%	5%	-2%
	Asia	22	-12%	-27%	-40%	-27%	-49%	-55%	33%	4%	9%
	Latin America	24	-8%	-19%	-34%	-22%	-37%	-54%	1%	0%	0%
	Middle East and Africa	6	-11%	-24%	-30%	-24%	-54%	-50%	17%	-5%	-6%

Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for “all” respondents

Changes in LCOE by Respondent Group: ***Fixed-Bottom Offshore Wind, 2014 to 2050***

Fixed-Bottom Offshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		110	**-10%**	**-30%**	**-41%**	**-20%**	**-43%**	**-53%**	**0%**	**0%**	**-17%**
By Lead / Larger group	Leading	15	-15%	-35%	-51%	-29%	-53%	-62%	8%	-3%	-21%
	Larger	95	-10%	-29%	-40%	-19%	-42%	-53%	0%	0%	-15%
By type of organization	Research	38	-10%	-26%	-39%	-20%	-43%	-51%	6%	0%	-12%
	Wind deployment	16	-11%	-36%	-45%	-23%	-53%	-58%	-4%	-12%	-25%
	Equipment manufacturer	12	-4%	-9%	-41%	-7%	-32%	-51%	3%	0%	-11%
	Other private sector	32	-12%	-29%	-40%	-20%	-43%	-55%	0%	0%	-16%
	Other	12	-10%	-32%	-41%	-17%	-43%	-54%	-3%	-4%	-22%
By applications evaluated	Offshore only	28	-11%	-36%	-44%	-24%	-49%	-56%	-2%	-12%	-22%
	Both onshore and offshore	82	-10%	-28%	-39%	-18%	-42%	-53%	2%	0%	-14%
By type of expertise	Wind energy markets	77	-12%	-31%	-41%	-21%	-45%	-55%	-1%	0%	-19%
	Systems level	59	-10%	-31%	-41%	-19%	-43%	-54%	0%	0%	-17%
	Subsystem level	30	-10%	-29%	-39%	-18%	-43%	-53%	2%	1%	-13%
By familiarity with region	North American	65	-8%	-27%	-39%	-18%	-42%	-53%	0%	0%	-15%
	Europe	79	-11%	-32%	-42%	-20%	-43%	-53%	1%	0%	-16%
	Asia	21	-14%	-29%	-44%	-26%	-47%	-56%	-1%	-4%	-23%
	Latin America	11	-11%	-28%	-39%	-15%	-42%	-52%	-1%	0%	-28%
	Middle East and Africa	6	-6%	-25%	-38%	-10%	-37%	-53%	-1%	-3%	-17%

Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for "all" respondents

Changes in LCOE by Respondent Group: *Floating Offshore Wind, 2014 to 2050*

Floating Offshore wind (LCOE relative to expert-specific 2014 baseline)											
Respondent Group		Number of respondents	Median scenario for typical LCOE (median expert response)			Low scenario for typical LCOE (median expert response)			High scenario for typical LCOE (median expert response)		
			2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
All		44	**6%**	**-25%**	**-38%**	**-11%**	**-45%**	**-53%**	**25%**	**5%**	**-6%**
By Lead / Larger group	Leading	6	-5%	-38%	-50%	-23%	-54%	-64%	28%	2%	-13%
	Larger	38	7%	-15%	-31%	-11%	-40%	-50%	23%	5%	-5%
By type of organization	Research	17	7%	-26%	-31%	-11%	-45%	-48%	18%	8%	-4%
	Wind deployment	7	5%	-25%	-38%	-13%	-47%	-55%	28%	5%	-9%
	Equipment manufacturer	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Other private sector	15	5%	-20%	-39%	-14%	-44%	-53%	19%	0%	-5%
	Other	5	13%	-15%	-44%	-9%	-39%	-55%	29%	9%	-6%
By applications evaluated	Offshore only	13	8%	-25%	-39%	-11%	-45%	-56%	25%	5%	-9%
	Both onshore and offshore	31	5%	-20%	-31%	-11%	-44%	-52%	24%	4%	-5%
By type of expertise	Wind energy markets	29	5%	-31%	-42%	-20%	-45%	-53%	19%	0%	-12%
	Systems level	31	6%	-25%	-38%	-10%	-45%	-53%	26%	5%	-6%
	Subsystem level	16	0%	-17%	-31%	-11%	-43%	-48%	13%	4%	-4%
By familiarity with region	North American	27	5%	-20%	-31%	-11%	-45%	-53%	22%	4%	-5%
	Europe	31	8%	-15%	-38%	-11%	-40%	-53%	28%	13%	-5%
	Asia	9	7%	-15%	-31%	-12%	-34%	-44%	27%	13%	-1%
	Latin America	4	13%	-4%	-23%	-8%	-4%	-36%	26%	13%	2%
	Middle East and Africa	2	-4%	-22%	-31%	-23%	-34%	-42%	13%	-3%	-9%

Note: Colors refer to whether and the degree to which the LCOE estimate is lower (green) or higher (red) than for "all" respondents

Changes in LCOE Components by Respondent Group: *Onshore Wind, 2014 to 2030*

Onshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)									
Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	**CapEx**	**OpEx**	**Capacity Factor**	**Project Life**	**WACC**
All		134	**-24%**	**-12%**	**-9%**	**10%**	**10%**	**0%**
By Lead / Larger group	Leading	17	-27%	-17%	-17%	10%	10%	0%
	Larger	117	-24%	-11%	-9%	10%	10%	0%
By type of organization	Research	38	-25%	-11%	-14%	14%	25%	0%
	Wind deployment	22	-22%	-11%	-8%	11%	0%	-1%
	Equipment manufacturer	22	-23%	-3%	-4%	8%	5%	0%
	Other private sector	39	-26%	-15%	-11%	11%	10%	0%
	Other	13	-24%	-15%	-8%	10%	0%	0%
By applications evaluated	Onshore only	52	-24%	-11%	-8%	10%	0%	0%
	Both onshore and offshore	82	-24%	-14%	-12%	11%	15%	0%
By type of expertise	Wind energy markets	94	-27%	-14%	-11%	11%	10%	0%
	Systems level	74	-26%	-15%	-11%	9%	10%	0%
	Subsystem level	36	-24%	-15%	-8%	11%	13%	0%
By familiarity with region	North American	93	-25%	-11%	-8%	14%	10%	0%
	Europe	77	-23%	-15%	-10%	9%	15%	0%
	Asia	22	-27%	-17%	-12%	4%	13%	0%
	Latin America	24	-19%	-9%	0%	8%	0%	0%
	Middle East and Africa	6	-24%	-11%	-13%	9%	13%	0%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for “all” respondents

Changes in LCOE Components by Respondent Group: *Fixed-Bottom Offshore, 2014 to 2030*

Fixed-Bottom Offshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)								
Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	**CapEx**	**OpEx**	**Capacity Factor**	**Project Life**	**WACC**
All		110	**-30%**	**-14%**	**-9%**	**4%**	**15%**	**-10%**
By Lead / Larger group	Leading	15	-35%	-18%	-7%	11%	25%	-8%
	Larger	95	-29%	-14%	-9%	4%	15%	-10%
By type of organization	Research	38	-26%	-17%	-9%	7%	0%	-5%
	Wind deployment	16	-36%	-18%	-8%	9%	23%	-20%
	Equipment manufacturer	12	-9%	-4%	-2%	0%	0%	0%
	Other private sector	32	-29%	-15%	-13%	4%	20%	-10%
	Other	12	-32%	-10%	-4%	4%	13%	-20%
By applications evaluated	Offshore only	28	-36%	-11%	-13%	7%	20%	-17%
	Both onshore and offshore	82	-28%	-16%	-9%	4%	13%	-1%
By type of expertise	Wind energy markets	77	-31%	-14%	-9%	7%	20%	-10%
	Systems level	59	-31%	-17%	-9%	7%	15%	-9%
	Subsystem level	30	-29%	-17%	-13%	3%	25%	0%
By familiarity with region	North American	65	-27%	-13%	-9%	4%	10%	-5%
	Europe	79	-32%	-17%	-12%	7%	20%	-10%
	Asia	21	-29%	-18%	-13%	4%	20%	-10%
	Latin America	11	-28%	-11%	-9%	4%	20%	0%
	Middle East and Africa	6	-25%	-10%	0%	4%	23%	-13%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for "all" respondents

Changes in LCOE Components by Respondent Group: ***Floating Offshore Wind, 2014 to 2030***

Floating Offshore wind (LCOE component values in 2030 relative to expert-specific 2014 baseline)								
Respondent Group		Number of respondents	Median scenario for typical LCOE					
			LCOE	**CapEx**	**OpEx**	**Capacity Factor**	**Project Life**	**WACC**
All		44	**-25%**	**-5%**	**-8%**	**9%**	**25%**	**-5%**
By Lead / Larger group	Leading	6	-38%	-10%	-9%	20%	25%	-15%
	Larger	38	-15%	-5%	-7%	8%	23%	0%
By type of organization	Research	17	-26%	-7%	-9%	9%	25%	0%
	Wind deployment	7	-25%	-3%	5%	2%	25%	-20%
	Equipment manufacturer	0	NA	NA	NA	NA	NA	NA
	Other private sector	15	-20%	-8%	-7%	7%	16%	-3%
	Other	5	-15%	0%	-7%	11%	0%	-5%
By applications evaluated	Offshore only	13	-25%	0%	-9%	11%	25%	-15%
	Both onshore and offshore	31	-20%	-8%	-7%	7%	25%	0%
By type of expertise	Wind energy markets	29	-31%	-12%	-9%	9%	25%	-5%
	Systems level	31	-25%	-3%	-7%	11%	25%	-4%
	Subsystem level	16	-17%	-4%	-8%	4%	25%	0%
By familiarity with region	North American	27	-20%	-2%	-9%	7%	25%	-7%
	Europe	31	-15%	0%	-5%	9%	25%	-3%
	Asia	9	-15%	-7%	0%	10%	25%	0%
	Latin America	4	-4%	-6%	0%	3%	0%	10%
	Middle East and Africa	2	-22%	-10%	-6%	22%	8%	8%

Note: Colors refer to whether and the degree to which the factor change will result in LCOE estimates that are lower (green) or higher (red) than for “all” respondents

Typical Turbine Characteristics in 2030 by Respondent Group: ***North American Projects***

North America														
			Onshore				Fixed-Bottom Offshore				Floating Offshore			
Number of all respondents	Respondent Group		n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)
77	**All North America**		71	3.25	115	135	37	9	115	170	18	9	120	190
69	By Lead / Larger group	Larger	63	3.25	115	135	31	9	125	170	16	9	115	180
8		Leading	8	3.5	115	125	6	8	115	190	2	10	125	210
52	By type of expertise	Wind energy markets	47	3.25	115	125	24	9	125	190	11	11	125	190
46		Systems level	44	3.25	115	135	22	9	115	170	4	9	120	180
23		Subsystem level	23	3.25	115	135	12	9	120	190	8	9	120	190
35	By applications evaluated	Onshore only	34	3.25	115	135		NA	NA	NA		NA	NA	NA
5		Offshore only		NA	NA	NA	4	11	125	200	3	11	125	210
37		Both onshore and offshore	37	3.25	115	125	33	9	115	170	15	9	115	170
22	By type of organization	Research	20	3.25	115	125	17	9	115	190	11	9	125	190
16		Wind deployment	14	3.5	130	140	2	12	130	210	2	12	130	210
14		Equipment manufacturer	14	3.25	125	145	4	12	155	200	0	NA	NA	NA
21		Other private sector	19	2.75	105	125	13	7	100	170	4	9	95	170
4		Other	4	3	115	115	1	7	155	150	1	9	170	170

Note: Colors refer to whether turbine size is larger (green) or smaller (red) than for “all” respondents

Typical Turbine Characteristics in 2030 by Respondent Group: ***European Projects***

Europe														
			Onshore				Fixed-Bottom Offshore				Floating Offshore			
Number of all respondents	Respondent Group		n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)	n	Turbine capacity (MW)	Hub height (m)	Rotor diameter (m)
73	**All Europe**		49	3.75	115	130	58	11	125	190	20	11	125	190
61	By Lead / Larger group	Larger	41	3.75	120	135	50	11	125	190	18	10	125	190
12		Leading	8	3.25	115	110	8	10	130	150	2	11	125	200
53	By type of expertise	Wind energy markets	34	3.5	115	125	42	11	125	190	14	10	125	190
34		Systems level	23	4.25	115	135	9	11	125	190	13	11	125	190
13		Subsystem level	9	3.25	125	130	13	11	125	190	5	9	115	170
12	By applications evaluated	Onshore only	10	3.75	115	115		NA	NA	NA		NA	NA	NA
22		Offshore only		NA	NA	NA	20	11	125	190	8	11	125	190
39		Both onshore and offshore	39	3.75	125	135	38	11	135	190	12	9	125	180
20	By type of organization	Research	17	3.75	115	135	17	11	125	170	4	10	125	190
14		Wind deployment	7	4.75	125	135	12	11	125	210	5	9	115	190
9		Equipment manufacturer	6	3.75	130	145	7	11	135	190	0	NA	NA	NA
20		Other private sector	12	3.5	115	125	15	11	125	190	8	11	125	190
10		Other	7	3.25	115	125	7	11	135	190	3	11	135	190

Note: Colors refer to whether turbine size is larger (green) or smaller (red) than for “all” respondents

Relative Impact on LCOE Reductions in 2030 by Respondent Group: ***Onshore Wind***

Onshore																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	129	112	17	37	22	22	36	12	89	75	21	24	6	90	74	35
Increased rotor diameter such that specific power declines	58%	62%	39%	68%	68%	60%	51%	33%	60%	56%	50%	52%	50%	58%	61%	62%
Rotor design advancements	45%	46%	38%	47%	45%	64%	35%	33%	43%	49%	48%	54%	60%	40%	52%	46%
Increased tower height	33%	33%	33%	31%	32%	45%	30%	33%	36%	28%	33%	54%	17%	36%	28%	36%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	32%	35%	17%	47%	24%	27%	21%	46%	29%	39%	36%	21%	33%	31%	32%	35%
Improved component durability and reliability	31%	31%	31%	39%	19%	23%	31%	42%	26%	39%	48%	29%	60%	31%	32%	28%
Increased energy production due to new transmission to higher wind speed sites	31%	32%	22%	22%	38%	33%	31%	38%	36%	25%	32%	35%	33%	35%	31%	35%
Extended turbine design lifetime	29%	29%	25%	31%	27%	32%	24%	33%	24%	40%	38%	25%	20%	28%	29%	31%
Operating efficiencies to increase plant performance	28%	29%	24%	31%	14%	27%	32%	33%	24%	32%	43%	21%	67%	30%	26%	25%
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	28%	30%	12%	19%	45%	36%	28%	8%	31%	24%	24%	46%	0%	31%	34%	26%
Turbine and component manufacturing standardization, efficiencies, and volume	27%	30%	12%	21%	14%	48%	32%	17%	20%	36%	43%	29%	60%	24%	34%	29%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	27%	27%	29%	32%	18%	32%	24%	27%	29%	28%	33%	38%	17%	26%	34%	31%
Integrated turbine-level system design optimization	23%	23%	21%	36%	10%	32%	15%	10%	20%	28%	20%	17%	0%	20%	30%	26%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	21%	20%	24%	17%	14%	14%	26%	38%	16%	32%	32%	29%	50%	23%	20%	23%
Large variety of alternative turbine designs to suit site-specific conditions	17%	18%	12%	19%	10%	33%	8%	25%	16%	15%	24%	13%	17%	18%	15%	20%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	17%	19%	0%	22%	14%	27%	8%	11%	16%	17%	24%	25%	0%	16%	19%	17%
Maintenance process efficiencies	17%	16%	18%	22%	10%	9%	14%	36%	10%	22%	14%	8%	0%	18%	12%	11%
Tower design advancements	14%	16%	6%	12%	19%	14%	14%	17%	15%	13%	5%	22%	20%	14%	17%	18%
Economies of scale through increased project size	12%	12%	17%	5%	14%	14%	19%	8%	8%	15%	15%	13%	0%	13%	18%	17%
Nacelle components design advancements	12%	12%	14%	12%	14%	9%	15%	8%	10%	12%	15%	13%	0%	11%	17%	15%
Installation and transportation equipment advancements	12%	11%	19%	18%	5%	14%	11%	8%	14%	9%	10%	21%	20%	13%	16%	26%
Innovative non-conventional turbine designs	12%	13%	0%	12%	14%	22%	8%	0%	14%	13%	21%	10%	0%	11%	16%	20%
Maintenance equipment advancements	10%	10%	12%	9%	10%	5%	11%	30%	8%	13%	14%	8%	0%	12%	8%	9%
Foundation and support structure manufacturing standardization, efficiencies, and volume	10%	11%	0%	18%	5%	15%	6%	0%	6%	14%	10%	13%	0%	6%	15%	12%
Foundation and support structure design advancements	10%	11%	0%	18%	10%	0%	8%	9%	6%	11%	5%	4%	0%	8%	11%	11%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	9%	9%	11%	14%	5%	5%	5%	23%	7%	14%	9%	8%	17%	10%	13%	12%
Installation process efficiencies	9%	9%	6%	15%	10%	0%	11%	0%	6%	11%	10%	13%	20%	8%	14%	11%
Reduced fixed operating costs, excluding maintenance	5%	4%	12%	3%	0%	5%	5%	17%	1%	6%	5%	0%	0%	3%	1%	3%
Lower decommissioning costs	1%	1%	0%	0%	5%	0%	0%	0%	1%	1%	0%	4%	0%	1%	0%	0%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Relative Impact on LCOE Reductions in 2030 by Respondent Group: ***Fixed-Bottom Offshore***

BERKELEY LAB

Fixed-Bottom Offshore																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	98	83	15	33	15	9	30	11	56	74	20	11	6	70	6	29
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	55%	57%	47%	55%	67%	44%	50%	64%	50%	58%	45%	73%	50%	61%	54%	52%
Foundation and support structure design advancements	53%	55%	36%	44%	60%	67%	47%	73%	53%	51%	50%	73%	80%	53%	51%	45%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	49%	51%	33%	46%	56%	44%	42%	67%	44%	49%	45%	55%	33%	53%	47%	38%
Economies of scale through increased project size	48%	49%	40%	46%	50%	44%	57%	30%	46%	47%	40%	64%	60%	51%	44%	38%
Improved component durability and reliability	48%	48%	50%	56%	53%	33%	41%	45%	46%	49%	50%	73%	40%	45%	56%	52%
Installation process efficiencies	46%	49%	29%	41%	56%	22%	47%	70%	47%	45%	50%	73%	50%	46%	46%	55%
Installation and transportation equipment advancements	44%	46%	36%	39%	44%	44%	50%	45%	46%	45%	55%	64%	20%	43%	43%	48%
Foundation and support structure manufacturing standardization, efficiencies, and volume	43%	48%	8%	42%	38%	44%	45%	45%	39%	45%	42%	55%	20%	46%	42%	43%
Extended turbine design lifetime	36%	35%	43%	24%	56%	33%	33%	55%	26%	42%	45%	55%	40%	41%	37%	34%
Turbine and component manufacturing standardization, efficiencies, and volume	36%	40%	8%	30%	50%	22%	38%	40%	30%	37%	26%	45%	20%	36%	35%	32%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	35%	38%	20%	31%	56%	22%	32%	33%	31%	38%	25%	36%	17%	39%	30%	24%
Integrated turbine-level system design optimization	33%	37%	7%	39%	23%	38%	33%	20%	30%	40%	33%	40%	25%	32%	38%	36%
Rotor design advancements	32%	32%	36%	33%	27%	33%	36%	27%	33%	35%	42%	55%	20%	26%	38%	39%
Maintenance process efficiencies	32%	32%	33%	28%	27%	33%	33%	45%	25%	34%	30%	36%	17%	32%	32%	34%
Maintenance equipment advancements	30%	30%	27%	31%	40%	11%	27%	36%	19%	32%	25%	36%	17%	31%	26%	34%
Operating efficiencies to increase plant performance	29%	28%	33%	31%	27%	33%	24%	36%	23%	32%	25%	45%	17%	26%	25%	24%
Increased rotor diameter such that specific power declines	27%	29%	14%	28%	27%	33%	28%	13%	26%	30%	35%	45%	0%	26%	33%	32%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	25%	28%	7%	20%	20%	44%	29%	17%	24%	30%	37%	45%	17%	22%	23%	34%
Increased energy production due to new transmission to higher wind speed sites	21%	20%	27%	21%	20%	33%	19%	20%	21%	22%	20%	36%	40%	22%	20%	11%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	21%	23%	7%	24%	15%	33%	17%	18%	27%	21%	26%	45%	20%	14%	24%	24%
Nacelle components design advancements	19%	20%	14%	16%	21%	13%	28%	9%	26%	16%	26%	40%	20%	19%	20%	31%
Innovative non-conventional turbine designs	17%	20%	0%	16%	14%	33%	17%	10%	20%	17%	26%	10%	25%	15%	21%	24%
Tower design advancements	12%	11%	14%	16%	7%	11%	10%	9%	9%	13%	10%	9%	20%	9%	13%	10%
Reduced fixed operating costs, excluding maintenance	10%	10%	7%	3%	29%	11%	7%	10%	7%	12%	11%	18%	0%	10%	9%	17%
Increased tower height	6%	6%	7%	6%	0%	11%	7%	9%	11%	5%	10%	18%	0%	8%	9%	14%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	5%	6%	0%	9%	0%	0%	7%	0%	5%	6%	5%	0%	25%	1%	9%	10%
Large variety of alternative turbine designs to suit site-specific conditions	5%	6%	0%	3%	6%	0%	0%	30%	7%	5%	10%	18%	50%	6%	4%	3%
Lower decommissioning costs	2%	3%	0%	0%	14%	0%	0%	0%	2%	1%	0%	0%	0%	3%	2%	4%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Relative Impact on LCOE Reductions in 2030 by Respondent Group: ***Floating Offshore***

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Floating Offshore																	
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise			
Wind technology, market, or other change	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Number of respondents	41	37	4	15	7	0	14	5	26	29	8	3	2	28	29	14
Foundation and support structure design advancements	80%	78%	100%	80%	86%	NA	79%	80%	77%	76%	63%	33%	0%	79%	83%	79%
Installation process efficiencies	78%	76%	100%	80%	57%	NA	86%	80%	88%	69%	75%	100%	50%	79%	72%	79%
Foundation and support structure manufacturing standardization, efficiencies, and volume	68%	69%	50%	43%	86%	NA	79%	80%	54%	75%	75%	67%	0%	70%	57%	43%
Economies of scale through increased project size	65%	64%	75%	71%	71%	NA	64%	40%	72%	61%	75%	100%	50%	61%	64%	69%
Installation and transportation equipment advancements	63%	65%	50%	60%	43%	NA	79%	60%	77%	59%	75%	100%	50%	64%	62%	71%
Increased turbine capacity and rotor diameter (thereby maintaining specific power)	59%	54%	100%	47%	71%	NA	57%	80%	62%	55%	63%	100%	50%	61%	59%	57%
Improved component durability and reliability	58%	56%	75%	50%	86%	NA	50%	60%	54%	57%	75%	67%	100%	67%	64%	71%
Increased competition among suppliers of components, turbines, Balance of Plant services, installation, and operations and maintenance	46%	49%	25%	33%	57%	NA	43%	80%	42%	48%	50%	100%	50%	57%	41%	21%
Reduced financing costs and project contingencies due to lower risk profile, greater accuracy in energy production estimates, improved risk management, and increased industry experience and standardization	46%	46%	50%	40%	43%	NA	50%	60%	42%	45%	50%	67%	50%	46%	38%	36%
Rotor design advancements	45%	44%	50%	53%	57%	NA	31%	40%	52%	43%	63%	67%	50%	39%	50%	64%
Integrated turbine-level system design optimization	44%	41%	75%	60%	14%	NA	43%	40%	42%	48%	50%	67%	50%	43%	45%	57%
Turbine and component manufacturing standardization, efficiencies, and volume	40%	44%	0%	21%	57%	NA	43%	60%	38%	43%	38%	100%	50%	44%	36%	21%
Extended turbine design lifetime	39%	41%	25%	33%	57%	NA	36%	40%	38%	38%	50%	67%	50%	43%	41%	50%
Maintenance process efficiencies	35%	36%	25%	29%	14%	NA	50%	40%	38%	36%	63%	67%	100%	41%	32%	50%
Innovative non-conventional turbine designs	34%	32%	50%	47%	0%	NA	43%	20%	38%	31%	50%	33%	100%	32%	41%	57%
Increased rotor diameter such that specific power declines	32%	31%	33%	36%	14%	NA	38%	25%	29%	38%	38%	33%	0%	27%	41%	46%
Increased energy production due to new transmission to higher wind speed sites	29%	30%	25%	27%	57%	NA	14%	40%	35%	24%	38%	67%	50%	32%	28%	21%
Tower design advancements	28%	25%	50%	40%	14%	NA	31%	0%	28%	29%	50%	33%	0%	18%	32%	50%
Nacelle components design advancements	28%	25%	50%	27%	29%	NA	31%	20%	40%	18%	38%	33%	0%	29%	29%	50%
Maintenance equipment advancements	25%	25%	25%	7%	14%	NA	36%	60%	23%	29%	38%	67%	100%	30%	21%	14%
Reduced total development costs and risks from greater transparency and certainty around siting and permitting approval timelines and procedures	20%	22%	0%	20%	0%	NA	29%	20%	23%	25%	57%	67%	50%	21%	14%	29%
Operating efficiencies to increase plant performance	18%	14%	50%	7%	0%	NA	23%	60%	16%	22%	38%	67%	50%	22%	15%	21%
Improved plant-level layout through understanding of complex flow and high-resolution micro-siting	15%	11%	50%	20%	0%	NA	8%	40%	12%	11%	0%	0%	0%	18%	15%	14%
Increased tower height	15%	14%	25%	13%	0%	NA	15%	40%	16%	14%	13%	33%	0%	21%	18%	21%
Large variety of alternative turbine designs to suit site-specific conditions	12%	14%	0%	13%	0%	NA	7%	40%	8%	14%	13%	33%	50%	11%	7%	0%
Innovative non-conventional plant-level layouts that could involve mixed turbine ratings, hub heights and rotor diameters	12%	14%	0%	20%	0%	NA	7%	20%	8%	17%	13%	33%	50%	7%	10%	7%
Reduced fixed operating costs, excluding maintenance	8%	9%	0%	0%	0%	NA	15%	20%	4%	12%	14%	0%	0%	7%	8%	7%
Lower decommissioning costs	3%	3%	0%	0%	0%	NA	7%	0%	0%	4%	14%	0%	50%	4%	4%	8%

Note: Colors refer to the relative rating of each advancement possibility within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated advancement and red a lower-rated advancement)

Broad Drivers for Low LCOE by Respondent Group: ***Onshore and Offshore Wind***

Ranking of Broad Drivers for Lower Onshore LCOE in 2030																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Driver	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Learning with market growth	33%	30%	47%	39%	30%	10%	32%	54%	31%	35%	48%	32%	67%	34%	24%	25%
Research and development	32%	32%	25%	32%	33%	48%	26%	17%	38%	24%	19%	26%	0%	28%	36%	42%
Increased competion and decreased risk	16%	16%	19%	16%	15%	14%	19%	17%	9%	24%	14%	22%	17%	16%	21%	17%
Eased wind project and transmisison siting	14%	15%	7%	11%	14%	14%	16%	17%	15%	11%	10%	13%	17%	15%	14%	17%

Note: Colors refer to the relative rating of each broad driver within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated driver and red a lower-rated driver)

Ranking of Broad Drivers for Lower Offshore LCOE in 2030																
Percent of experts rating item "Large expected impact"		By Lead / Larger group		By type of organization					By familiarity with region					By type of expertise		
Driver	All Respondents	Large	Leading	Research	Wind deployment	Equipment manufacturer	Other private sector	Other	North America	Europe	Asia	Latin America	Middle East & Africa	Wind energy markets	Systems level	Subsystems level
Learning with market growth	33%	34%	27%	27%	31%	33%	42%	33%	32%	35%	52%	36%	50%	30%	33%	27%
Research and development	32%	33%	29%	41%	31%	36%	23%	27%	31%	26%	15%	18%	33%	32%	31%	37%
Eased wind project and transmisison siting	25%	25%	29%	19%	25%	27%	29%	36%	24%	29%	33%	45%	0%	30%	25%	30%
Increased competion and decreased risk	5%	3%	14%	8%	6%	0%	3%	0%	7%	4%	0%	0%	17%	4%	7%	7%

Note: Colors refer to the relative rating of each broad driver within each respondent category (i.e., colors are coded based on each column, with green designating a higher-rated driver and red a lower-rated driver)